COST REDUCTION STUDY OF BICYCLE BY USING DFA METHODS

HO KA HUI

Report submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering with Manufacturing Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2012

UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

We certify that the project entitled "Cost Reduction Study Of Bicycle By Using DFA Methods " is written by Ho Ka Hui. We have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. We herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

Mr. Azim Mohd Arshad .....

Examiner Signature

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

.....

Ahmad Nasser Mohd Rose

Supervisor/Lecturer

Date:

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurently submitted for award of other degree.

.....

HO KA HUI

ME08056

Date: 20th June 2012

DEDICATION

To my beloved mother and father and to all of you,

Thank you for the support during my research…

ACKNOWLEDGEMENTS

First of all, deepest gratitude goes to my project supervisor Mr. Ahmad Nasser Mohd Rose, for his incisive guidance, supervision, continuous encouragement and particularly for the valuable time he has devoted throughout this research. I had benefited in numerous way from his supervision. I am thankful for his tolerance of my many mistakes and the time spent correcting me. His continued support led me to the right way.

My sincere thanks goes to Mr Hadi Bin Abdul Salaam for providing valuable information throughout this study, teaching me and having valuable discussion, guidance to make my study to be more expeditious and fluent. Certainly, not to forget the UMP Faculty of Mechanical Engineering for providing the software needed in this study.

I would also like to thank my loving parents, sister and brothers for their support in both financial and spiritual, love, and sacrifice throughout this study. Special thanks are given to my fellow friends and senior. I would like to acknowledge their comments and suggestions, which was crucial for the successful completion of this study.

Lastly, for each and every one who involved either directly or indirectly in this final year project, their contribution is highly appreciated. The kindness corporation and support from all of the above mentioned people would always be remembered.

ABSTRACT

Design for Assembly (DFA) is a tool for simplifying product design which enables to provide a good design to be easily manufactured and assembled. The objectives of this study are to evaluate and improve the design efficiency of a selected bicycle. The study was carried out through few processes which are disassembly of bicycle, assemble of bicycle parts and at the same time tabulate assembly time according to the methods used last but not the least, calculation of design efficiency by using the synthesis data. The good indication of design evaluation using DFA is able to reduce number of parts and simplify the assembly process. Design evaluation on bicycle was analysed by Boothroyd-Dewhurst DFA and Hitachi AEM methods. The evaluation result on existing efficiency design of bicycle shows 26.97 % by BD method and 69.83 % by Hitachi method. Furthermore the improvement designs also improve the assembly time. This result shows the DFA method was successfully applied to the selected bicycle.

ABSTRAK

"Design for Assembly" adalah salah satu kaedah diamana ia digunakan untuk memudahkan reka bentuk produk dan membolehkan reka bentuk produk sedia ada bertambah baik supaya mudah untuk pemasangan di industri. Objektif kajian ini adalah untuk menilai dan memperbaiki kecekapan reka bentuk basikal yang dipilih. Kajian ini dijalankan melalui beberapa proses termasuk menyah-pasang basikal, memasang balik bahagian-bahagian basikal dan menjadualkan masa pemasangan untuk basikal yang dipasang. Pengiraan kecekapan reka bentuk untuk basikal juga dilakukan dengan adanya data untuk masa pemasangan basikal. Penilaian reka bentuk menggunakan "*DFA*" dapat mengurangkan bilangan bahagian-bahagian pada basikal dan memudahkan proses pemasangan. Penilaian reka bentuk pada basikal telah dianalisis oleh "*Boothroyd-Dewhurst DFA*" dan "*Hitachi AEM*". Hasil penilaian ke atas reka bentuk kecekapan basikal yang sedia ada menunjukkan 26.97 % oleh kaedah "*Boothroyd-Dewhurst DFA*" dan 69,83 % dengan kaedah "*Hitachi AEM*". Selain itu, masa pemasangan untuk reka bentuk basikal yang telah diperbaik berjaya dikurangkan. Keputusan ini menunjukkan bahawa kaedah "*DFA*" telah berjaya dalam meningkatkan prestasi pamasangan untuk basikal yang dipilih.

TABLE OF CONTENTS

CHAPTER 4 RESULTS AND DISCUSSIONS

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

E_d	Functional efficiency
E_{ma}	Design efficiency
N_{min}	Theoretical minimum number of parts
T_a	Basic assembly time = 3 second
T_h	Handling time
T_{ma}	Estimated time to complete the assembly of the product
T_i	Insertion time

LIST OF ABBREVIATIONS

AEM	Assemblability Evaluation Method
CAD	Computer-aided design
CAE	Computer-aided engineering
CE	Concurrent Engineering
DFA	Design for Assembly
DFM	Design for Manufacture
DFMA	Design for Manufacture and Assembly
NM	Theoretical minimum number of part
TM	Total manually assembly time

CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

"Optimization" is the key word for production engineer and plant operators to meet success. According to Steve Jobs, when he is making a design for his new Apple product, "less is more" is the key to make his product distinctive. A great industrial design should be clean and simple. Similar concept goes to Design for Assembly (DFA). According to Boothroyd, DFA is a methodology for evaluating part designs and the overall design of an assembly. It is a structured way to identify unnecessary parts in an assembly and to determine assembly times and achieve cost optimization. It is a support method that encourages product development in teams, in order to maximize productivity. If a design is easier to produce and assemble, it can be done in less time, so it is less expensive. Hence, in this whole report, there are techniques, methods and guidance of DFA to show how to achieve the target. In this chapter, problem statement, objectives, scopes, expected result as well as report arrangement are clearly stated.

1.1 PROJECT BACKGROUND

The dilemma faced by some companies was the inability to have return of investment after investing in product development. The possible cause might be errors that are caused by human, machines, parts delivery not delivered on time and also poor design. As a result, these factors had influenced the manufacturing and assembly cost. Regardless

what kind of production they have, these companies definitely need immediate changes to reverse the current situation or they will face continuously deficit. Some companies gain profit while producing products but the others did not gain as much profit when producing similar products. This problem is due to the assembly and manufacturing process cost majority of the investment capital.

Traditionally, the designers only take care in designing the product without considering how the product can be made or the difficulties in making the product. This attitude is termed as “over-the-wall-approach” where the designer is sitting on one side of the wall and throwing design over the wall to the manufacturing engineer, who has to deal with manufacturing difficulties. To cope with this situation, the designer team must throw away the “over-the-wall-approach” and work together with manufacture engineer at the designing stage. This teamwork is called concurrent engineering team where team members consists of design engineers, manufacturing engineers, cost accountants and marketing and sales professionals. With these multi-disciplinary team members, plenty of problems regarding manufacturing difficulties can be solved at designing stage with the help of analysis tool – the DFA. The DFA is important in that it potentially can reduce the estimated 15-70 % of manufacturing cost that is attributable to assembly. Besides the reduction in cost, DFA promises additional benefits in increased quality, increased reliability, and shorter manufacturing time (Wu, T. and O'Grady, P. 1999).

1.2 PROBLEM STATEMENT

Bicycle is considered as one type of transportation modes. It helps the usage in every aspect of the daily requirement. Besides as a transportation mode, a bicycle can also be used as an exercise equipment. According to Barnes and Krizek (2005) and Massachusetts Statewide Bicycle Transportation Plan on year 1990, bicycle demand keeps increasing. The assembly of bicycles needs to be competent to cope with the growing industry. On the other hand, the cost of producing a bicycle worth to be studied in order to let consumer to enjoy a lower cost product but in the same time maintaining the bicycle quality.

1.3 OBJECTIVES

The objectives of this study are:

i. To evaluate the design efficiency for existing product.
ii. To reduce the part count of the existing product.
iii. To propose a new design with improve in design efficiency of the product.

1.4 SCOPES OF STUDY

The chosen product is a mountain bike which named Predator the Millenium edition assembled by Probike. Only major assemblies are considered and the sub-assembly of which minor parts area assumed to come as ready in the major assembly line. The bicycle used is in Figure 1.1. There are many listed DFA techniques in the field. For this research, the DFA technique used is Boothroyd-Dewhurst design for assembly (DFA) and Hitachi Assemblability Evaluation Method (AEM). In this study, only the assembly cost of the bicycle is consider although there are many elements that sums up the total cost of product.

Apart of that, to visualize the components to be improved in 3-dimensional, the engineering drawing software, Solid Works is used. With the aid of Solid Works, a clearer understanding of components in the product can be obtained. The finite element analysis using Autodesk Algor simulation software is used to identify weak points of redesign parts so that the new design for product is proven practical.

Figure 1.1: Product chosen in doing research.

1.5 EXPECTED RESULT

The total assembly time and assembly cost of selected bicycle is evaluated using Boothroyd- Dewhurst manual assembly method and Hitachi AEM. The design efficiency of original product is calculated so that comparison can be made with the improved design. It is expected that by using both methods, the design efficiency of improved design bicycle will increase. The increment in design efficiency is led by the reduction in parts of product. Since the total part for assembly is reduced, cost reduction on redesign product can be achieved through reduction of assembly time. This simplify product can be produced and assemble in less time, so it is less expensive.

1.6 REPORT ARRANGEMENT

This report is divided into five chapters. Chapter one include introduction, background of study, problem statements, objectives and explanation of scope of study. The expected result is also explained briefly in this chapter.

For chapter two, literature review of study is done. The meaning of all the key words in the title is reviewed. The previous and current situations differ with and without application of concurrent engineering which is DFMA from design stage until the production stage are discussed. Then, brief introduction to various methods of DFMA and how DFMA is related to cost reduction are discussed. Here, the general design guidelines are also discussed. Last but not the least, the related studies of other researchers are reviewed and a summary table has been made.

In chapter three, an over view of methodology for the entire study is explained. First, the design of study and framework are listed in a flow chart. Then, the concepts of both DFA methods used are discussed including the introductions to manual calculation of assembly time using Boothroyd Dewhurst DFA method and Hitachi AEM. The elimination and redesign parts chosen are based on some criteria and they are discussed in this chapter too. Lastly in this chapter, an example of how to obtain the assembly time of a part is shown.

In chapter four, the design evaluation is done for both existing and redesign product. The dimensions of each disassembled parts of bicycle are measured and the orientation, which is alpha and beta also tabulated. It is then followed by the critiqued of every part to obtain the candidates for redesign purpose. After obtaining the theoretical minimum number of parts, manual calculation is used to determine total time for assembly, estimated cost, and not to forget the design efficiency. Design improvements are suggested. The redesign parts are then been modeled using CAD for better illustration. Lastly, the modeled parts are analyzed using finite element analysis software. In chapter five, the recommendations and conclusion are made.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

This chapter provides an overview of product design process, concurrent engineering, cost reduction and influence of design for assembly (DFA) methods to cost reduction. DFA principles are the structured design analysis tools that analyze product design from assembly prospective at early stage when doing a product design review. Only with the existing product evaluation then only a product can be further design to meet any requirement of the consumer. At the end of this chapter, a review of 10 products related to DFA and cost reduction studies by past researcher is done and a comparison chart of the techniques used more frequently is drawn.

2.1 PRODUCT DESIGN PROCESS

2.1.1. Traditional Process of Producing a Product

According to Boothroyd et al., (2002), traditionally the attitude of the designers has been “we design it, you built it”. This has also been term “over-the-wall-approach” as illustrated in Figure 2.1, where the designers sit at one side of the wall and throw their design to the manufacturing engineers over the wall who have to face the various manufacturing problem because they are not involve in the design stage.

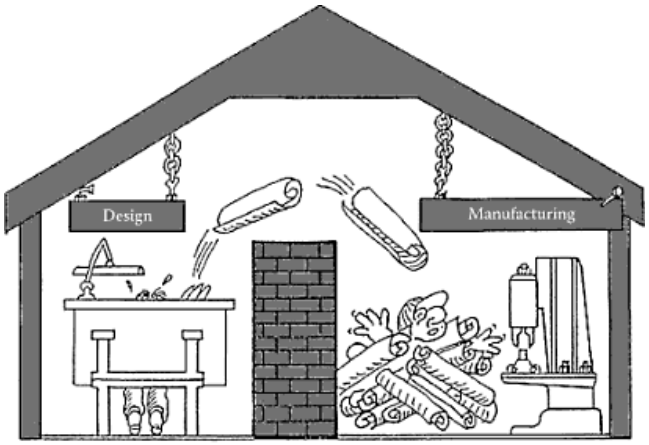


Figure 2.1: The “over the wall” design method.

Source: Boothroyd et al. (2002)

The sequences of designing and producing a product was first the detail conceptual sketches of the parts completed on the CAD workstation by the design engineers. Yet another interpretation of the word "design" would be the detailing of the materials, shapes, and tolerance of the individual parts of a product. It is an activity that starts with sketches of parts and assemblies. It then progresses to the CAD workstation, where assembly drawings and detailed part drawings are produced. These drawings are then passed to the manufacturing and assembly engineers whose job it is to optimize the processes used to produce the final product. Frequently, it is at this stage that manufacturing and assembly problems are encountered and requests are made for design changes. Sometimes these design changes are large in number and result in considerable delays in the final product release. Furthermore, the later the product design and development cycle changes occur, the more expensive they become. Therefore, not only is it important to take manufacture and assembly into account during product design, but also these considerations must occur as early as possible in the design cycle.

In order to overcome this problem, the design engineers and manufacturing engineers have to sit together and this team work can overcome a lot of problems during the manufacturing of product. This team is now called simultaneous engineering or concurrent engineering and they need analysis tools to help them study a propose design and also evaluate the product design from the point of view of manufacturability and cost.

2.1.2. Concurrent Engineering (CE)

Concurrent engineering is the practice of concurrently developing products and their design and manufacturing processes. If existing processes are to be utilized, then the product must be design for these processes. If new processes are to be utilized, then the product and the process must be developed concurrently. This requires knowing a lot about manufacturing processes and one of the best ways to do this is to develop products in multifunctional teams.

The main purpose of concurrent engineering is to shorten a product development time through a simultaneous time implementation of the several stages of the engineering activity in parallel and under a concurrent mode offering all information required by all elements of the product life cycle. An early consideration of manufacturing issues shortens product development time, minimizes development cost, and ensures a smooth transition into production for quick time to market (Belay, 2009). Among all the reasons, the most important and most concerning by a company is the cost reduction method. Applying Design for Manufacturing and Assembly methodologies in early stages of product design can reduce the number of parts in a product and thus reduce costs (Boothroyd et al., 2002).

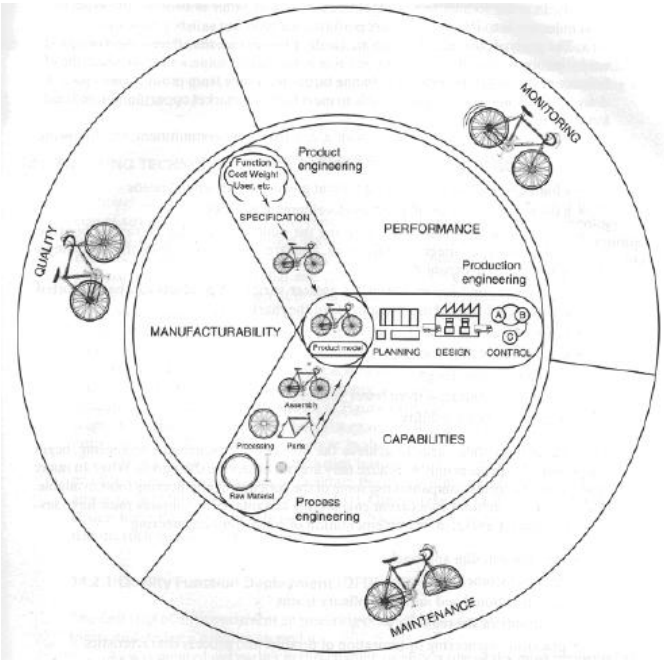


Figure 2.2: Concurrent engineering approach.

Source: Krumenauer et al. (2008)

2.2 COST REDUCTION

In order to compete in the current commercial environment a company should learn to react fast and effectively. Companies must produce greater product variety, at lower cost, all within a reduced product life cycle. The enterprises have to present their new product to the public rapidly and continuously. Meanwhile, they must keep their products with the low price and high quality. So, developing the new product to satisfy the consumers' requirements and make them appear in the market as soon as possible becomes the key to share more part of the cake of the market.

In order to achieve this, a concurrent engineering philosophy is often adopted. In many cases the main realization of this is Design for Manufacture and Assembly (DFMA).

There is a need for in-depth study of the architectures for DFMA systems in order that the latest software and knowledge-based techniques may be used to deliver the DFMA systems of tomorrow. This architecture must be based upon complete in order to survive and develop in the market.

2.2.1 Definition of Cost Reduction

Cost reduction can be explained as the operation of identifying and thus eliminate inessential and wasteful cost so that the profit of a business can be improved. However, the achievement of cost reduction in the unit of product manufactured is done without lower neither the quality nor function ability of the product. Hence, cost reduction should therefore not to be confused with cost saving and cost control. In other words, the essential characteristics and techniques and quality of the products are retained through improved methods and techniques used and thereby a permanent reduction in the unit cost is achieved.

In the point of view of how DFMA can help in cost reduction, the elimination of unnecessary elements from the design of the product has greatly aid in improve and simplify the assembly and manufacture procedure and hence the defects of products are reduce, thereby reduce the unit cost. There is a very important fact we must always bear in mind is that, the quality and usefulness of products remain unaffected, if not improved.

2.2.2 Influences of DFA in Cost Reduction

Design for Assembly DFA is a tool for early product design evaluation that simplifies the design concept through part reduction strategies and predicts assembly costs. DFA helps remove product costs without compromising function, while improving quality, reliability, and delivery times. DFA allows engineering teams to quantify their ideas and create more innovative products. Currently over 750 companies around the world use Boothroyd Dewhurst DFMA tools to reduce the total cost of product. (Nicholas, 2005)

Studies show that the design approaches affects the final cost of a new product more than any other factor. Figure 2.3 compares two traditional cost curves. One shows the influence on cost of a change in the project during the design phase and other shows the influence of these changes during the same period. Surveys show that, based on a traditional accounting, the cost of design for a new car represents approximately 5 % of the total. It is responsible for 70 % of the product cost, while the material, direct and indirect costs represent 30 % of the cost (as shown in Figure. 2.4). From the manufacturing perspective, less than 30 % of the product cost may be affected by improvements initiatives, starting from the point at which the product is already defined. So design has enormous influence in terms of power to compete on quality and cost. (Krumenauer, 2008)

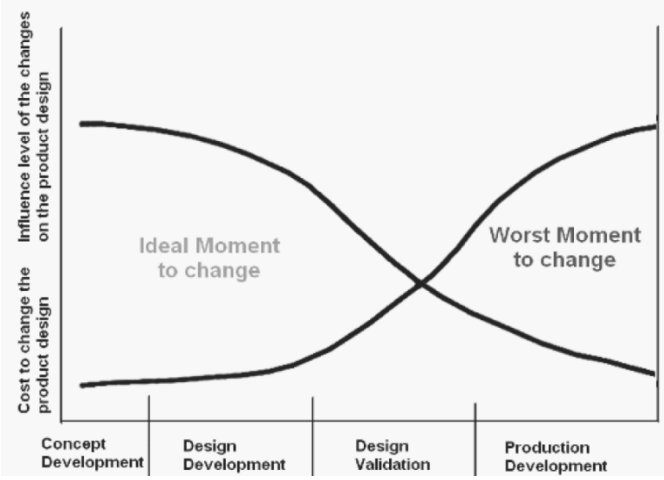


Figure 2.3: Concurrent engineering approach.

Source: Krumenauer et al. (2008)

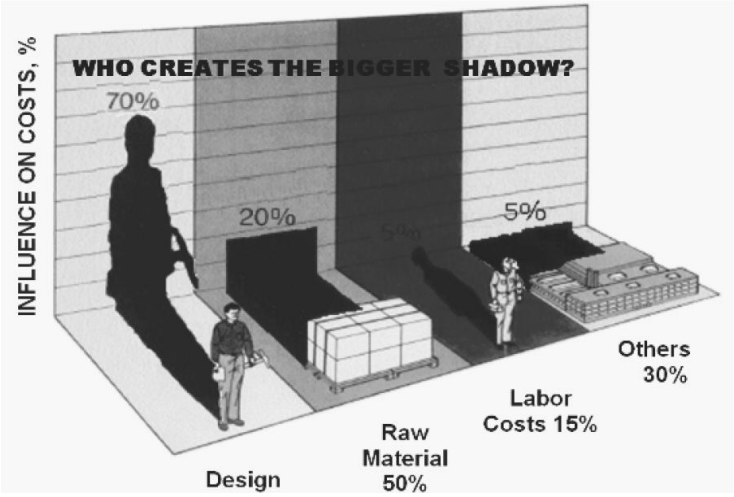


Figure 2.4: Costs influence level and the design.

Source: Boothroyd et al. (2002)

The importance of taking manufacture and assembly into account as early as possible in the design cycle is illustrated in Figure 2.5. This figure shows that extra time spent early in the design process is more than compensated for by savings in time when prototyping takes place. Thus, in addition to reducing product costs, the application of DFMA shortens the time to bring the product to market. As an example, Ingersoll-Rand Company reported that the use of DFMA software from Boothroyd Dewhurst, Inc., slashed product development time from two years to one. In addition, the simultaneous engineering team reduced the number of parts in a portable compressor radiator and oil-cooler assembly from 80 to 29, decreased the number of fasteners from 38 to 20, trimmed the number of assembly operations from 159 to 40 and reduced assembly time from 18.5 min to 6.5 min. Developed in June 1989, the new design went into full production in February, 1990. (Boothroyd et al., 2002)

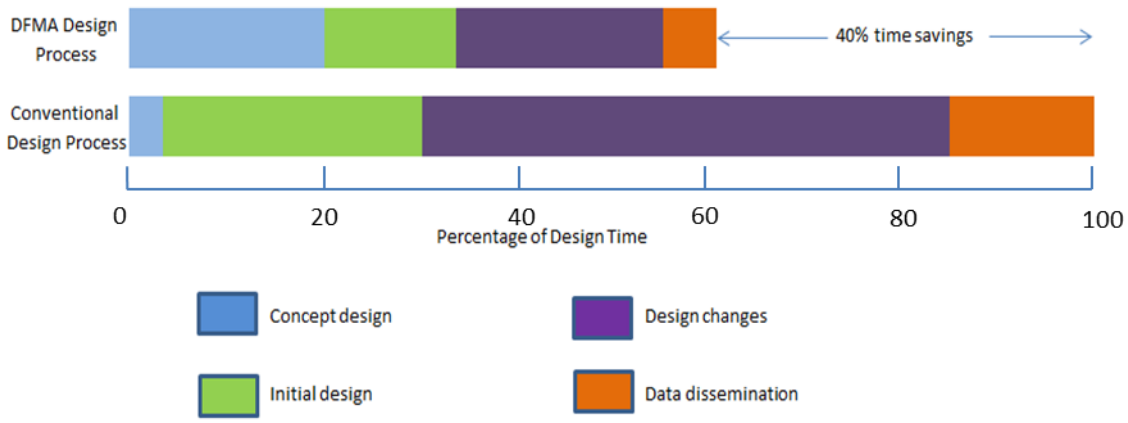


Figure 2.5: DFMA shortens the design process.

Source: Boothroyd et al. (2002)

2.3 GENERAL DESIGN GUIDELINES FOR MANUAL ASSEMBLY

According to Boothroyd et al. (2002), the manual assembly process can be divided into two which is part handling and insertion. This set of guidelines would point product designers towards simplicity of design in assembly point of view.

2.3.1. Design Guidelines for Part Handling

Component handling is the process of separating a part from bulk, and the grasping, transporting, orienting, and positioning it for placement in assembly. Factors that affect the ease of which a component is handled and positioned are:

i. Component's size
ii. Need for orientation
iii. Handling difficulties

In general, for ease of part handling, a designer should attempt to (Boothroyd et al., 2002):

i. Design parts that have end-to-end symmetry and rotational symmetry about the axis of insertion. If cannot be achieved, try to design parts having the maximum possible symmetry (Figure 2.6 a).
ii. Design parts that, in those instances where the part cannot be made symmetric, are obviously asymmetric (Figure 2.6 b).
iii. Provide features that will prevent jamming of parts that tend to nest or stack when stored in bulk (Figure 2.6 c).
iv. Avoid features that will allow tangling of parts when stored in bulk (Figure 2.6 d).
v. Avoid parts that stick together or are slippery, delicate, flexible, very small, or very large or that are hazardous to the handler (Figure 2.7)

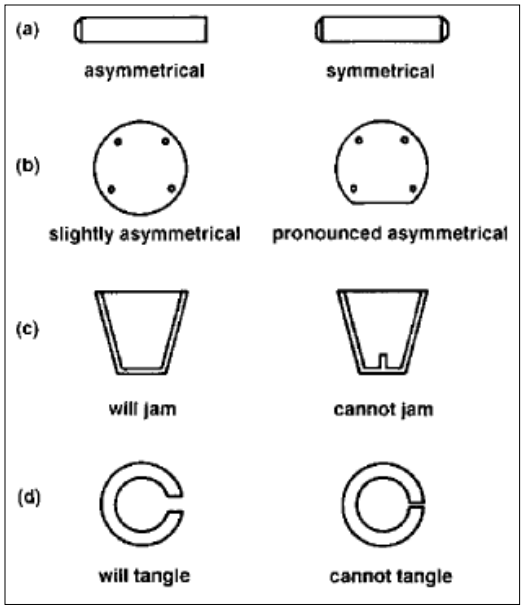


Figure 2.6: Geometrical features affecting part handling.

Source: Boothroyd et al. (2002)

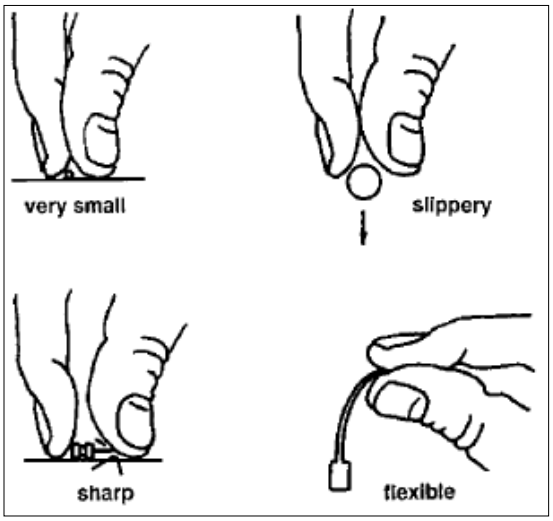


Figure 2.7: Some other features affecting part handling.

Source: Boothroyd et al. (2002)

2.3.2. Design Guidelines for Part Insertion and Fastening

For ease of insertion, a designer should attempt to:

i. Design so that there is little or no resistance to insertion and provide chamfers to guide insertion of two mating parts. Generous clearance should be provided, but care must be taken to avoid clearances that will result in a tendency for parts to jam or hang-up during insertion.

ii. Standardize by using common parts, processes, and methods across all models and even across product lines to permit the use of higher volume processes that normally result in lower product cost

iii. Use pyramid assembly- provides for progressive assembly about one axis of reference. In general, it is best to assemble from above.

iv. Avoid where possible, the necessity for holding parts down to maintain their orientation during manipulation of the subassembly or during the placement of another part. If holding down is required, then try to design so that the part is secured as soon as possible after it has been inserted.

v. Design so that a part is located before it is released. A potential source of problems arises from a part being placed where, due to design constrains, it must be released before it is positively located in the assembly. Under this circumstance, reliance is placed on the trajectory of the part being sufficiently repeatable to locate it consistently.

vi. When common mechanical fasteners are used the following sequences indicate the relative cost of different fastening process, listed in order of increasing manual assembly cost.

   a. Snap fitting
   b. Plastic bending
   c. Riveting
   d. Screw fastening

vii. Avoid the need to reposition the partially complete assembly in the fixture

2.3.3. Component Securing

Component securing is the process of physically attaching components to the partially built-up assembly using permanent or non-permanent joining processes securing may occur as part of the insertion process (e.g., installation of a threaded fastener) or it may be performed as a separate operation (e.g., adhesive bonding of joint). A component is designed for easy securing when it is located and retained upon insertion and requires no screwing or plastic deformation as part of the securing operation. Snap-fits, press-fits, spire nuts, and so forth are examples of components that are easy to secure.

2.3.4 Separate Operations

The separate operations include all assembly operations other than those directly associated with adding a part moving to another assembly surface, or performing an adjustment. Examples of separation operations are mechanical joining processes such as adhesive bonding, riveting, welding, and bolt tightening. Separate operations should be

avoided whenever possible because there are additional information contents like instructions, material handling, floor space, quality risk and so forth.

2.4 DESIGN FOR ASSEMBLY (DFA)

Design for Assembly is a methodology for evaluating part designs and the overall design of an assembly. It is a quantifiable way to identify unnecessary parts in an assembly and to determine assembly times and costs (Boothroyd et al., 2002). In the industry, products are being design with an excessive number of parts, costly and complex assembly procedures than it should be (Boothroyd et al., 2002). The establishments of DFA methodologies have proven successes within manufacturing business, and are able to highlight assembly issues (Miyakawa and Ohashi, 1986; Boothroyd and Dewhurst, 1989; Lucas Enrineering System Ltd, 1993).

Design for Assembly (DFA) is a new approach to facilitate development of efficient product designs in simplifies a product so that the cost of assembly is reduced (Vincent and Filippo, 2005). It act as the guidance for concurrent engineering design team to simplify product structure, reduce manufacturing and assembly cost, and to quantify the improvements. It is also a benchmarking tool to study competitors' products and quantify manufacturing and assembly difficulties. The product design has a significant impact to the manufacturing cost as well as the timescales. The recommendations suggested by the DFA methodologies can be summarized into the following (Boothroyd et al., 2002):

i. Eliminate the part. Parts such as screw, nut and spring are usually considered to be eliminated as much as possible.
ii. Combine the part with it mating part. This is due to recommendation of the Boothroyd's three criteria.
iii. Simplify the assembly operations. This includes consideration of the structure of product and designs each component.

2.5 DESIGN FOR ASSEMBLY METHODS

There are three well known quantitative evaluation techniques or also known as design for assembly (DFA) methods used in industry (DFA) which are Boothroyd-Dewhurst design for assembly method from USA, Lucas Hull design for assembly method from UK and Hitachi assemblability evaluation method from Japan.

2.5.1. Boothroyd-Dewhurst DFA Method

The Boothroyd-Dewhurst DFA evaluation focuses on establishing the cost of handling and inserting component parts. Regardless of the assembly system, parts of the assembly are evaluated in terms of ease of handling, ease of insertion and an investigation of parts reduction. The Boothroyd and Dewhurst DFA is an effective approach to improve the design efficiency of product. Boothroyd and Dewhurst DFA methodology has been recognized as a very useful tool in increasing competitiveness by reducing the part number of components, simplifying the product design structure and improving product design reliability. The guidelines for analyzing product for manual assembly Boothroyd and Dewhurst method are adopted and are suggested by Estorilio and Simiao (2006) as below:

i. To get the design details, engineering drawings, three dimensional models (3D), physical prototype or the own product.
ii. To disassembly the product and observe the sequence and how each part is disassembled. To consider the sub-assemblies as spare parts, identifying each one of them.
iii. To start the product re-assembly since the major part to the minor, writing the assembly time.
iv. To calculate the design efficiency through the following formula:
EP = 3 × NM/TM, being (EP: design efficiency, NM: parts number, and TM: assembly time).

v. Analyze the new design by repeating step 1 through 4 and gage improvements by comparing design efficiencies between current and modified design. Iterate until satisfied.

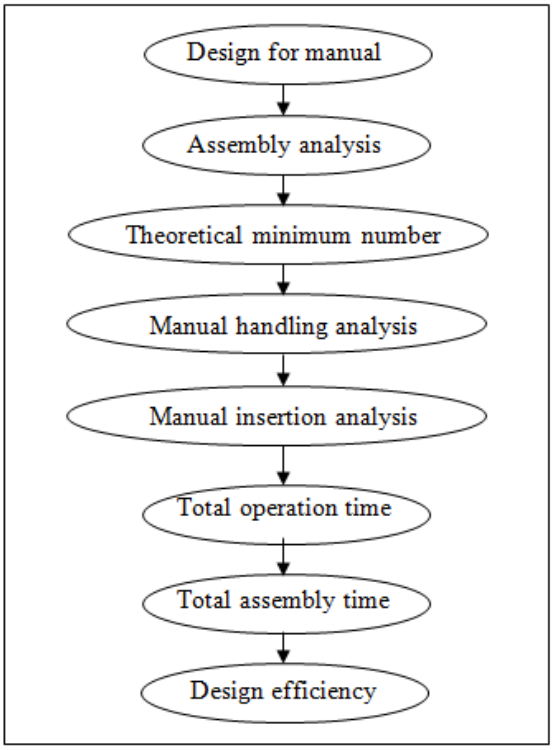


Figure 2.8: Boothroyd and Dewhurst DFA analysis.

Source: Boothroyd et al. (2002)

After evaluation of the design efficiency of a product, the necessary of eliminating redundant components of a product is done by examining whether each component exists as a separate part for fundamental reasons. The fundamental reasons are (Boothroyd and Dewhurst, 2002):

i. During operation of the product, does the part move relative to all other parts already assembled? Only gross motion should be considered – small motions that can be accommodated by elastic hinges, for example, are not sufficient for a positive answer.
ii. Must the part be of a different material or be isolated from all other parts already assembled? Only fundamental reasons concerned with material properties are acceptable.
iii. Must the part be separated from all those already assembled, because otherwise necessary assembly or disassembly of other separate parts would be impossible?

If the answer "yes" to at least one of the following three questions above for a part, the part is needed. Otherwise if the answer "no", the part is the candidate to be eliminated or combined with other part. The process of challenging the existence of each component in a product is the key to efficient assembly. Products that consists the minimum number of parts are enhanced for assembly and also provide knock-on benefits through reduces stock holding and inventory, reduced manufacturing or sourcing costs, and increased reliability.

Next task is to estimate the assembly time for the design and establish its efficiency rating in terms of assembly difficulty. This analysis is first to define the estimated time for handling the part according the weight, thickness, size, how it will be grasped and orientation of each part. Secondly is manual insertion analysis that used to estimate the insertion time for each part according the resistance and alignment during insertion and how the part is secured such as the part secured using snap fit or mechanical tools. The data are then tabulated by using a design for assembly worksheet as shown in Appendix i.

Then fourth and fifth step is to calculate the total operation time and the total assembly time. The formula is following below:

$$Total\ operation\ time\ in\ second\ =\ N(T\ h\ +\ Ti) \tag{2.1}$$

Where;

T h = handling time,

T_i = insertion time,

N = Number of operations.

$$Total\ assembly\ time\ (sec) =\ \Sigma\ total\ operation\ time\ of\ each\ part \tag{2.2}$$

The last step is the calculation of design efficiency. The design efficiency is obtained by using the formula below (Boothroyd et al., 2002):

$$Ema\ =\frac{Nmin\ \times\ Ta}{Tma} \tag{2.3}$$

Where;

N_{min} = theoretical minimum number of parts

T_a = basic assembly time = 3 second

T_{ma} = estimated time to complete the assembly of the product

2.5.2. Hitachi Assemblability Evaluation Method

The Assemblability Evaluation Method (AEM) is an effective tool developed by Hitachi, Ltd in the late of 1970 in Tokyo, Japan. The objective of Hitachi AEM is to facilitate design improvement by identifying weaknesses in product design at the earliest possible stage. This method developed by Miyakawa and Ohashi has been widely used by the Hitachi Group. It is based on the principle of "one motion for one part." By calculating the degree of difficulty of assembly operations and the estimation of assembly cost ratio, the product design weaknesses can be identified in the early design stage. The product design quality is analyzed quantitatively and weaknesses in the design's assembly producibility are highlighted. The AEM did not distinguish between manual, robot, and automated assembly. The theory and procedure of AEM are given as below (Wang, 1997):

i. Establish a symbol for each assembly operation X, the Hitachi method has approximately 20 elemental operations.
ii. For an assembly, a reasonable sequence and method of attachment for each part is assumed, and the attachment operations area expressed by the elemental operations.
iii. For each set of assembly parts, the total score E and the estimated assembly cost ratio

$$K = \frac{E}{Es} \tag{2.4}$$

are calculated, where E_s is the “standard” score from the original design or the competitor’s model.
iv. Assembly cost ratio (K) used to project elements of assembly cost.

This may be considered to be a measure of design efficiency where a score of 100 would represent a perfect design. Hitachi consider that an overall score E of 80 is acceptable and overall assembly cost ratio K less than 0.7 is acceptable.

2.6 PREVIOUS RESEARCH

This section summarizes some of the previous studies done by other researchers.

2.6.1 Diesel Engine

This research was carried out by Estorilio et al. (2006). The aim of study is to reduce manufacture and assembly cost of a diesel engine model manufactured in Curitiba so that this engine is economically feasible. The method used by the researchers to conduct this study is Boothroyd Dewhurst DFMA (Design for Manufacturing and Assembly) method. After the analysis of the engine design, it was identified that the production time is approximately 5 hours and 35 min, and the production capacity correspond to one engine in each 7 min. The results show an impact in the cost reduction of the subsystem chosen of 1.8 % and in the entire engine 0.7 %.

2.6.2 Pressure Vessel

In order to obtain a shorter product development cycle time for a pressure vessel through reduction in manufacturing and assembly time, research has been conducted by using Boothroyd-Dewhurst DFMA method and has come out with a positive result. The pressure vessel design was obtained from one of the oil and gas companies in Malaysia. Without considering the guideline of design for manufacture and assembly, the existing pressure vessel component quantity is 127, and the new design has just 108 components due to reduction of the skirt vent number from 3 to 2. The percentage of quantity reduction from the existing design is 14.96 %. Even though the reduction of component is small, but it still can give impact on assembly time, material cost and material handling cost.

The orientation time has a 6.06 % reduction, welding time 9.48 % reduction, insertion time 3.27 % reduction, total manual handling time 9.43 % reduction, and total operation time 9.42 % reduction. With that, it can reduce component assembly time and eventually can shorten the development time of pressure vessel. The design assembly

efficiency for existing vessel is 0.020 %. Improved vessel design efficiency is 0.022 %.The implementation of this approach has improved the company's performance and return of investment (Ismail et al., 2009).

2.6.3 Nail Puncher

According to journal entitled "Research on Collaborative Concept Design Integrating the Application of Virtual Reality and DFMA", the researcher used method of Boothroyd Dewhurst DFA to improve the design efficiency of the corresponding nail puncher from 0.179 to 0.401. Total operation time has a drastic decrease from 134.25 sec to 59.12 sec. This case study has proved to save assembly time by 75.13 sec, which is 22.2 % more efficient than the original design. And, in addition to cost reduction, the number of parts is also reduced from 15 to 10. However, what the case study results have revealed are not only the benefits on final product saving, but also the influences of the proposed approach on product development cycle time and cost. With the proper integration and application DFMA and VR visualized concept, the product concept development process can be considerably speed up. And, while the application of DFMA reduces the number of parts, the overall cost of molding, machining, engineering analysis, material, part storage and handling, and product structure management is usually reduced at the same time. (Justin, 2008)

2.6.4 White Goods Product

"The White Goods Part Designed Based on DFM/DFA Concepts in a Concurrent Engineering Environment" is a thesis published by Osiris et al., (2009). This paper demonstrates the applicability of the concepts of Concurrent Engineering and DFM/DFA (Design for Manufacturing and Assembly) in the development of products and parts for the White Goods industry in Brazil (major appliances as refrigerators, cookers and washing machines), showing one case concerning to the development and releasing of a component. Finally, it shows, shortly, how using these techniques as a solution had provided cost savings and reduction in delivery time.

To the first question, the answer was no since the part is a fixed stand where any of the parts would move and therefore it was not necessary to be isolated but could be fixed in the set to the others. The answer to the second questions is negative, as the parts did not need to be constructed from different materials of the set of parts. And finally, the third answer, as the previous ones, was negative, as there was no impeditive to assemble the parts to the others around.

2.6.5 Electric Wok

Robert et al. (2004) had carried out a case study on electric wok using Boothroyd Dewhurst DFA method and conceptual DFA analysis. Both method also show a decrease of part count of the existing product and reduce assembly time. Analysis by using Boothroyd Dewhurst DFA method leads to part count reduce from 33 to 19, original design efficiency is 24.41 % while revised design efficiency is 45.28 %. Analysis by conceptual DFA method lead to reduction of total 20 parts, total assembly time 91 sec only compare to the original assembly time 233.48 sec.

2.6.6 Heavy Duty Stapler

Robert et al. (2004) proposed that a product architecture-based technique can move DFA analysis to the conceptual design stage and produce reduced part count products similar to other post-design DFA techniques. The results illustrate two major benefits of the product architecture based DFA technique. The first is that conceptual DFA analysis leads to reduced part count products that are essentially equivalent to those resulting from a post-design DFA analysis such as Boothroyd and Dewhurst. The second benefit demonstrates the potential design cycle savings that can be achieved when a conceptual DFA analysis is executed. There is a reduction to 14 parts from the original 29 parts of the existing model. The assembly time will also decrease with decreasing number of parts. The manual design efficiency of the revised design is 47.1 %, for existing product is 20.6 %. Assembling 14 parts need only 89.17 sec but assembling the existing model needs 204.18 sec.

2.6.7 3-pin Soket

Zubir (2007) study Design for Automatic Assembly (DFAA) with Hitachi Assemblability Evaluation Method (AEM). In automatic assembly, the various individual assembly operations are generally carried out at separate workstations. For this method of assembly, a machine is required for transferring the partly completed assemblies from workstation to workstation, and a means must be provided to ensure that no relative motion exists between the assembly and the work heads or robot while the operations is being carried out.

The new design gives a good result in terms of total number of unique components. The original design which consists of 20 different types of components has been reduced to only 12 different types of components in the new design implemented. This indicates that total of 8 components in types have been eliminated with the reduction percentage of 40.0 %. The improvements concentrate on eliminating screw and changing it to snap fit and combining life, earth and neutral components. The assembly index for product level of the original design is 77.8 % meanwhile for the new design is 87.3 %. The difference in percentage of the assembly index for product level is 9.5 %. This contributes to an increase of 12.2 % in the assembly index. The increment has given an acceptable value for automatic assembly. The assembly index for part level of the original design is 62.3 % meanwhile for the new design is 71.8 %. The difference in percentage of the assembly index for product level is 9.5 %. This contributes to an increase of 15.2 % in the assembly index. The increment has given an acceptable value for automatic assembly. Part level index is more critical in measuring the design performance compare to product level index. It is because the part level evaluates every single components of the product regarding to all its design rules.

2.6.8 Car Seat

A study which was carried out by Ghazalli et al. (2008), on Proton Wira car seat by implementing Theory Inventive Problem Solving (TRIZ), Axiomatic Design (AD) and Boothroyd Dewhurst DF. There are 29 parts with different material and the total assembly times to assemble these components are 286.87 sec. After revising the car seat design, they are able to reduce the total components to 24 parts and assembly time needed is 236.51 sec. The authors had conclude that TRIZ and Axiomatic design is one of the methods that able to guide the designer on how to redesign a product systematically and qualitatively while the DFA considers the redesign from the quantitative perspective. Secondly, Integration of axiomatic design, TRIZ and DFA is able to aid the designer to generate the creativity in the assembly design. Thirdly, DFA set the guidelines on how to design a product with minimizes assembly cost. Their aim of this study is achieve which is to increase design efficiency, in order to produce an efficient and economic design.

2.6.9 Price Tagger

A study on product design improvement through design for Manufacture and Assembly (DFMA) and Theory of Inventive Problem Solving (TRIZ) has been done by Rozali (2010). This research has quantified the improvement by implementing DFMA method only, and implementing both DFMA and TRIZ method. The numbers of parts reduce from 30 to 22. Total assembly time decrease from 274.55 sec to 183.65 sec. Total assembly cost reduces from 26.68 cents to 17.8508 cents. Design Efficiency improves from 18.58 % to 27.78 %. While for the result of using TRIZ as additional method, design efficiency grows from 27.78 % to 36.97 %. It brought a better result compare with using only DFMA.

2.6.10 Sponge Mop

Mohamed (2010) has carried out a research on redesigning a sponge mop. The author has used Boothryod Dewhurst DFMA method together with the enhancement of Theory of Inventive Problem Solving (TRIZ). TRIZ is one of the Value Engineering (VE) systematic tools to improve the value of products by examination of function, by which designer can systematically solve problems and enhance decision-making. Design for Manufacture and Assembly (DFMA) is an approach to improve product performance and to simplify product. This project report describes work to integrate DFMA and TRIZ to improve and value added the current design of consumer product.

The effects of the improvements were dramatically viewed especially in the design efficiency. The value of 209.09 % increment shows that the implementing of Boothroyd-Dewhurst DFA methodology in product design will ensure in increasing the design efficiency of a product. Results from case studies showed that the integrating of DFMA and TRIZ can improve the product design efficiency value, minimize assembly complexity, reduce the overall assembly time and cost, and reduce the number of part in product improvement compared by just using single tool. By implementing DFMA only in the redesign strategy, the improvement of design efficiency is from 23.09 % to 71.37 %. However, the result gives more increment by considering DFMA together with TRIZ analysis. Which is the design efficiency become 80.46 % after the redesign have been done.

Table 2.1: Table of summary of previous research.

No	Author	Year of Publish	Product	Method	Results
1	Carla Estorilio and Marcelo César Simiao	2006	Diesel engine	Boothroyd-Dewhurst	Improve design efficiency from 23 % to 29 %
2	Ismail, A.R. et al.	2009	Pressure vessel	Boothroyd-Dewhurst	Improve design efficiency from 0.02 % to 0.022 %
3	Justin J.Y. Lin	2008	Nail Puncher	Boothroyd-Dewhurst	Improve design efficiency from 17.9 % to 40.1 %
4	Canciglieri Júnior, O. et al.	2009	White Goods Part	Boothroyd-Dewhurst	Improve design efficiency from 18.75 % to 69.23 %
5	Robert B.S. et al.	2004	Electric Wok	Boothroyd-Dewhurst	Improve design efficiency from 20.6 % to 37.46 %
6	Robert B.S. et al.	2004	Heavy Duty Stapler	Boothroyd-Dewhurst	Improve design efficiency from 24.41 % to 42.86 %.
7	Zubir, B.	2007	3-pin Soket	Lucas Hull	Assembly efficiency increase 9.5 %
8	Ghazalli, Z. et al.	2008	Car Seat	Boothroyd-Dewhurst	Improve design efficiency from 13.6 % to 15.22 %
9	Rozali, A.	2010	Price Tagger	Boothroyd-Dewhurst	Improve design efficiency from 23 % to 34.3 %
10	Mohamed,M	2010	Sponge Mop	Boothroyd-Dewhurst & TRIZ	Improve design efficiency from 23.09 % to 71.37 %

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter presents the overview of methodology of final year project. Start from design of study, followed by framework of the study in the flow chart diagram. The detail guidance of performing product assembly evaluation by Boothroyd-Dewhurst DFA method and Hitachi AEM were also discussed as well as example for each of the DFA approaches was shown.

3.2 DESIGN OF THE STUDY

After confirming with the product chosen, previous researchers' result must be taken by searching for available journals and references from internet, library and databases available in library. The common keywords that had been used in searching and browsing the journals are for examples 'Parts Elimination', 'Information Content', 'Boothroyd-Dewhurst', 'DFA', 'DFMA', 'Design Efficiency', 'Concurrent Engineering', 'Insertion/Handling Code', 'Cost Estimation in Product Design', 'Snap-fits', 'Design Guidelines', 'Assembly time' , 'Product Design Improvement' and 'Quantifying Design Improvement'. There are about ten journals mentioned and discuss in the Literature Review chapter, they are amongst the references that had been used during this study. Reference and text book in other hand are used in understanding the concept and detail methods to evaluating the products. At the same time, meetings and lecture session from university's DFMA curriculum syllabus are beneficial to this study.

Then, this study proceeds with design of the framework and project methodology. In this section, the overview of methods that had been used in completing the study is reviewed in general. Here, the manual calculating method to determine assemblies' handling and insertion code are discussed. Besides that, the important '3 Questions' of Boothroyd-Dewhurst DFA are reviewed before the method for selecting the best alternative design is being discussed.

The study progress is carried on with design evaluation for existing parts. In this section, the data gathered form each parts that have been disassembled are presented. In here, parts dimension, orientation and criticism are included. The evaluations of the design are divided into two phases. Phase one is to evaluate the design efficiency of existing product by critique the existing product design from assembly point of view. Evaluation will suggest candidates for elimination or modifications candidates on the design. Then, a CAD modeling is made to illustrate how the part should be redesign. On the other hand, phase two is concern about analysis and selection of new proposed designs. The justifications for each new design also discussed in this section.

3.3 FRAMEWORK OF THE STUDY

DFA is a structured design analysis tools that analyze product design from assembly prospective. First, an existing product design is analyzed. The insights gained from the evaluation are then used to develop and refine existing product design. The redesign alternatives aimed to eliminate parts for the ease of parts assembly and at the same time improve product quality. The step-by-step procedures are as Figure 3.1.

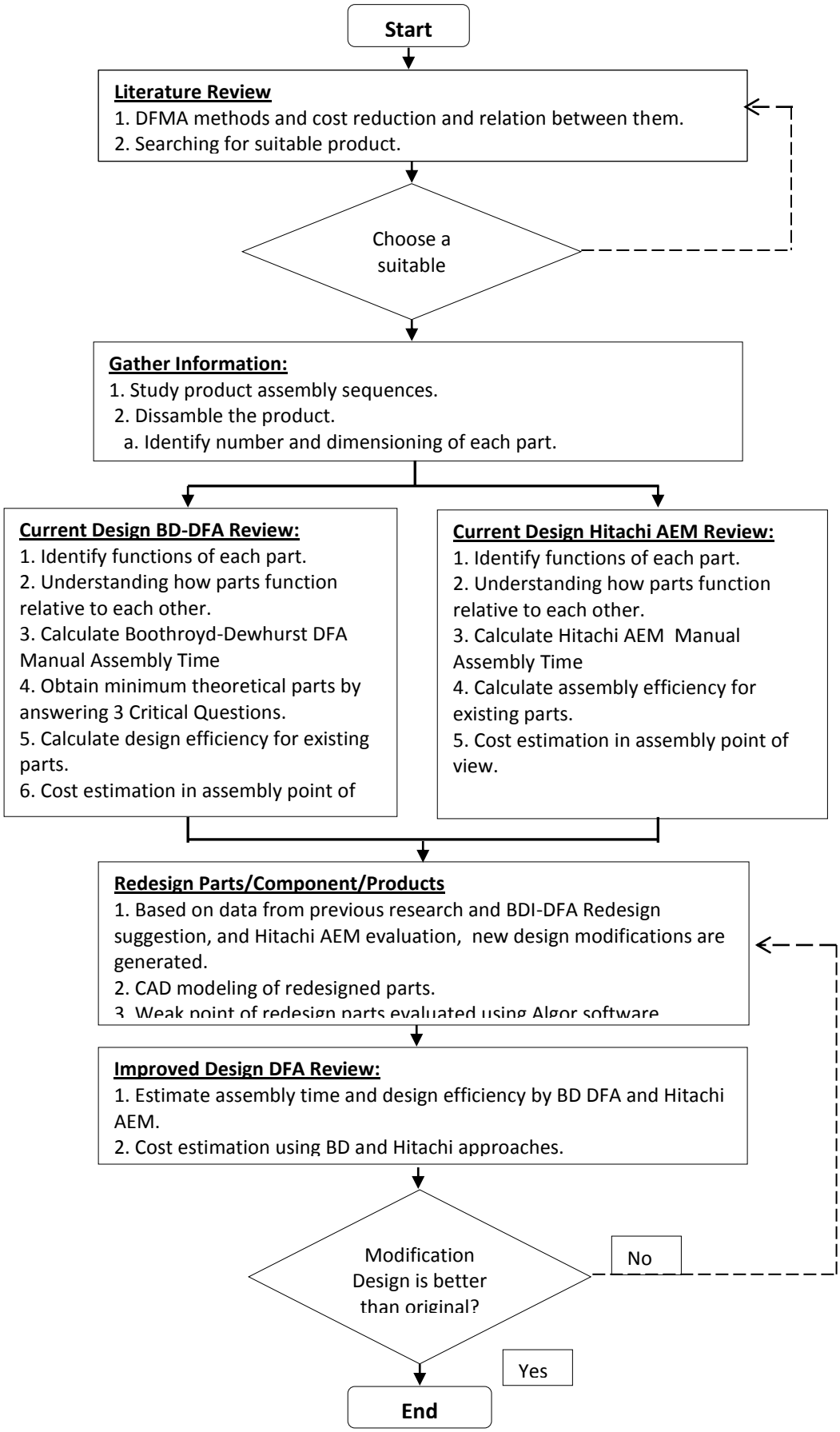


Figure 3.1: Framework of the study.

3.3.1. Identifying and selection of product

Bicycle is chosen in this study to perform cost reduction study using DFA methods. This product is chosen mainly because of the bicycle is a product which contain more than 20 mechanical parts. Analysis can be done more easily because of the mechanical background. Bicycle is an environmental friendly vehicle as well as an exercising gadget for the people. The usage of bicycle is encouraged by a lot of parties either governmental or the non-governmental organization. For example at George Town Penang, the state government has launched a "Car Free Day" every Sunday since 11st December 2011. Beach Street will be off limits to motor vehicles from the China Street junction to the Union Street junction, while both Bishop Street and Church Street will be closed from the Beach Street junction to the Penang Street junction starting from 7am to 5pm. It is less stress on the streets and pedestrians and cyclists can breathe a lot easier. The cyclists can ride freely too. Hence the demand for bicycle will be definitely high because of this promotion.

3.3.2. Current Design Review

In order to perform this study, it is crucial to have a technical insight into the product and understanding of how parts of product works and functioned due to the point of view of observer might be subjective in term of determining a good product design and ease of assembly, a few exercise on other improved product or example are strongly recommended.

Information gathering of chosen product is important before product disassembly process is initiated. The product must be disassembled part by part to get the detail number of component. Then measure each parts by using manual measuring tool for example venire caliper to get the detail dimension of each part. Photo is captured for each disassembly of parts. Besides, the orientations of every part which are alpha symmetry and beta symmetry data are gathered.

3.3.3. Boothroyd-Dewhurst DFA Manual Evaluation

The criteria for reducing parts count per assembly, established by Boothroyd and Dewhurst (2002) involve negative answers to the following questions (Figure 3.2):

i. Does the part move relative to all other parts already assembled in the normal operating mode?
ii. Must the part be of a different material or be isolated from other parts already assembled?
iii. Must the part be separate from all other parts already assembled because otherwise necessary assembly or disassembly of other parts would be impossible?

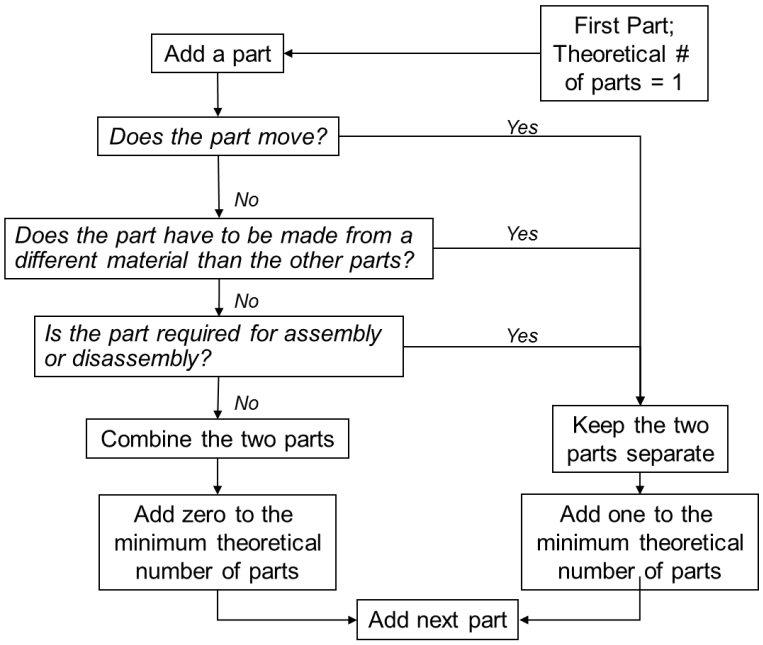


Figure 3.2: 3 questions to determine theoretical minimum number of parts.

Source: Boothroyd et al. (2002)

Table 3.1: Example of Design for Assembly Manual Worksheet.

Part ID no	Part Name	Number of times the operation is carried out consecutively	Two digit Manual Handling Code	Manual Handling time per part	Two digit Manual insertion code	Manual insertion time per part	Operation time	Theoretical minimum number of parts
				T_h		T_i	$T_h + T_i$	0/1
						TOTAL:	T_{ma}	N_{min}

Source: Boothroyd et al. (2002)

The example of DFA Manual Worksheet as in Table 3.1 will be filled with handling and insertion two digit codes and time for each part of the product. With the understanding of how parts work and relate to each other in normal operating mode, the handling and insertion difficulties of the part are define by the code obtained from Boothroyd-Dewhurst DFA Manual Handling (Figure 3.4) and Insertion Table (Figure 3.5).

Assembly operations always involve at least two component parts which are the part to be inserted and the receptacle into which the part is inserted. Orientation involves the proper alignment of the part to be inserted relative to the corresponding receptacle and can always be divided into two distinct operations which are alignment of the axis of the part that corresponds to the axis of insertion and the rotation of the part about this axis. It is therefore convenient to define two kinds of symmetry for a part (Boothroyd et al., 2002):

i. Alpha symmetry: depends on the angle through which a part must be rotated about an axis perpendicular to the axis of insertion to repeat its orientation.
ii. Beta symmetry: depends on the angle through which a part must be rotated about the axis of insertion to repeat its orientation.

The alpha and beta rotational symmetries for various parts are as shown in Figure 3.3
.

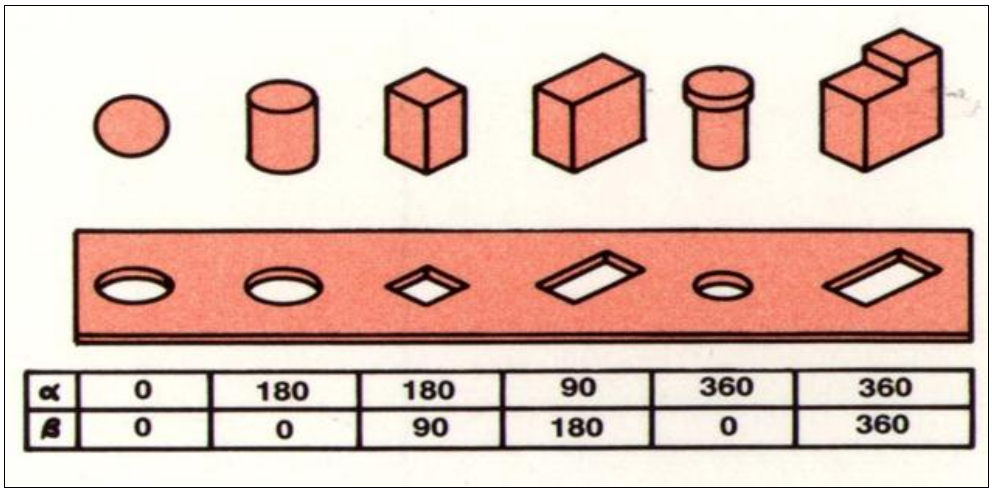


Figure 3.3: Alpha and beta rotational symmetries for various parts.

Source: Boothroyd et al. (2002)

After manual insertion and handling code are determined, the insertion and handling time are obtained. Then, the assembly times for each part are summed up and the total assembly time can be estimated.

MANUAL HANDLING—ESTIMATED TIMES (seconds)

Key:

ONE HAND

parts can be grasped and manipulated by one hand without the aid of grasping tools		parts are easy to grasp and manipulate					parts present handling difficulties (1)				
		thickness > 2 mm			thickness ≤ 2 mm		thickness > 2 mm			thickness ≤ 2 mm	
		size >15 mm	6 mm ≤ size ≤15 mm	size <6 mm	size >6 mm	size ≤6 mm	size >15 mm	6 mm ≤ size ≤15 mm	size <6 mm	size >6 mm	size ≤6 mm
		0	1	2	3	4	5	6	7	8	9
$(\alpha+\beta) < 360°$	0	1.13	1.43	1.88	1.69	2.18	1.84	2.17	2.65	2.45	2.98
$360° \le (\alpha+\beta) < 540°$	1	1.5	1.8	2.25	2.06	2.55	2.25	2.57	3.06	3	3.38
	2	1.8	2.1	2.55	2.36	2.85	2.57	2.9	3.38	3.18	3.7
$540° \le (\alpha+\beta) < 720°$	3	1.95	2.25	2.7	2.51	3	2.73	3.06	3.55	3.34	4
$(\alpha+\beta) = 720°$											

ONE HAND with GRASPING AIDS

parts can be grasped and manipulated by one hand but only with the use of grasping tools			parts need tweezers for grasping and manipulation								parts need standard tools other than tweezers	parts need special tools for grasping and manipulation
			parts can be manipulated without optical magnification				parts require optical magnification for manipulation					
			parts are easy to grasp and manipulate		parts present handling difficulties (1)		parts are easy to grasp and manipulate		parts present handling difficulties (1)			
			thickness > 0.25 mm	thickness ≤ 0.25 mm	thickness > 0.25 mm	thickness ≤ 0.25 mm	thickness > 0.25 mm	thickness ≤ 0.25 mm	thickness > 0.25 mm	thickness ≤ 0.25 mm		
			0	1	2	3	4	5	6	7	8	9
$\alpha \le 180°$	$0 \le \beta \le 180°$	4	3.6	6.85	4.35	7.6	5.6	8.35	6.35	8.6	7	7
	$\beta = 360°$	5	4	7.25	4.75	8	6	8.75	6.75	9	8	8
$\alpha = 360°$	$0 \le \beta \le 180°$	6	4.8	8.05	5.55	8.8	6.8	9.55	7.55	9.8	8	9
	$\beta = 360°$	7	5.1	8.35	5.85	9.1	7.1	9.55	7.85	10.1	9	10

TWO HANDS for MANIPULATION

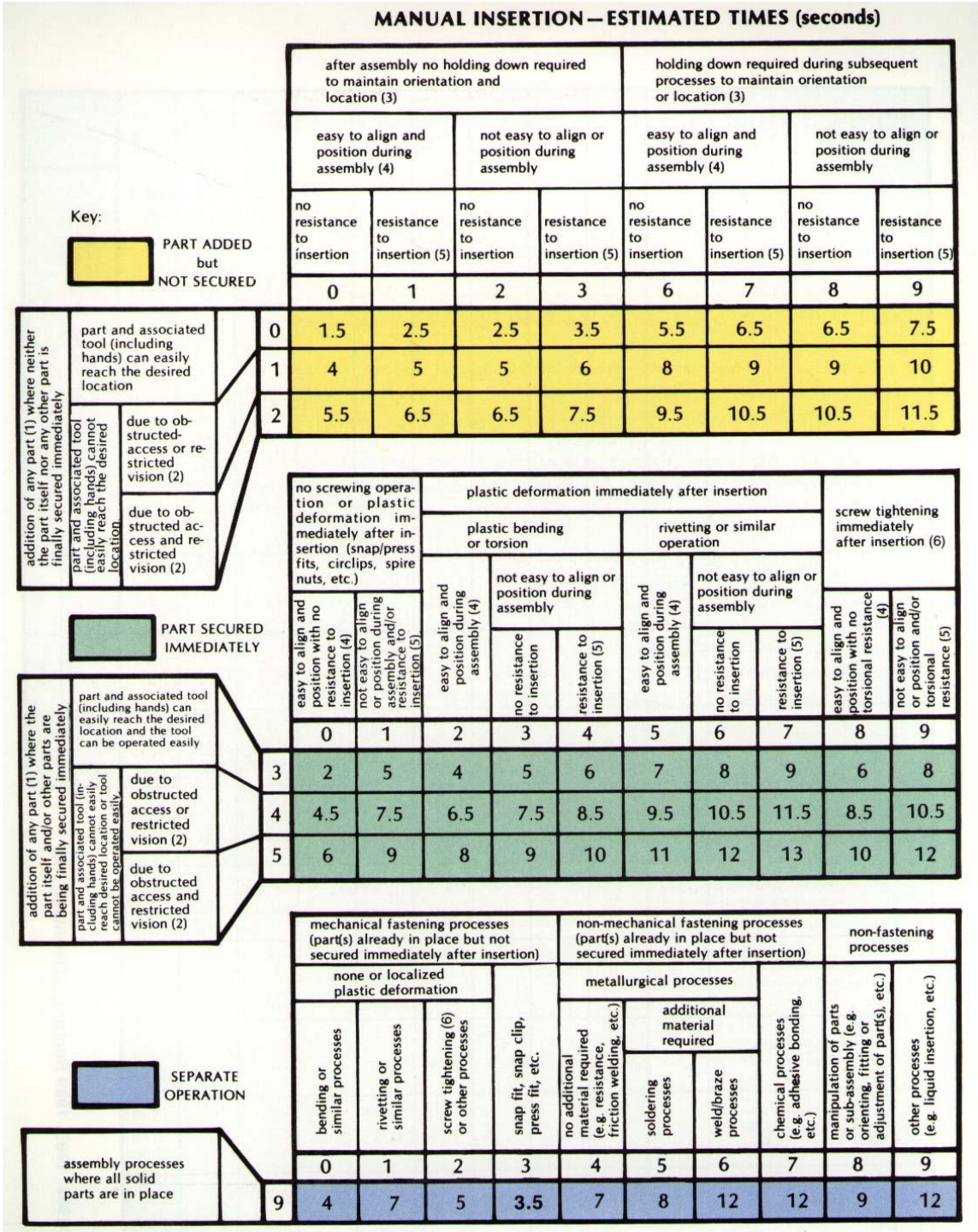
		parts present no additional handling difficulties					parts present additional handling difficulties (e.g. sticky, delicate, slippery, etc.) (1)				
		$\alpha \le 180°$			$\alpha = 360°$		$\alpha \le 180°$			$\alpha = 360°$	
		size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm	size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm
		0	1	2	3	4	5	6	7	8	9
parts severely nest or tangle or are flexible but can be grasped and lifted by one hand (with the use of grasping tools if necessary) (2)	8	4.1	4.5	5.1	5.6	6.75	5	5.25	5.85	6.35	7

TWO HANDS required for LARGE SIZE

		parts can be handled by one person without mechanical assistance									
		parts do not severely nest or tangle and are not flexible								parts severely nest or tangle or are flexible (2)	parts need special tools for grasping and manipulation
		part weight < 10 lb				parts are heavy (> 10 lb)					
		parts are easy to grasp and manipulate		parts present other handling difficulties (1)		parts are easy to grasp and manipulate		parts present other handling difficulties (1)			
		$\alpha \le 180°$	$\alpha = 360°$	$\alpha \le 180°$	$\alpha = 360°$	$\alpha \le 180°$	$\alpha = 360°$	$\alpha \le 180°$	$\alpha = 360°$		
		0	1	2	3	4	5	6	7	8	9
two hands required for grasping and transporting parts	9	2	3	2	3	3	4	4	5	7	9

Figure 3.4: Boothroyd-Dewhurst DFA Manual Handling Table.

Source: Boothroyd et al. (2002)



MANUAL INSERTION — ESTIMATED TIMES (seconds)

Key:
- PART ADDED but NOT SECURED
- PART SECURED IMMEDIATELY
- SEPARATE OPERATION

		after assembly no holding down required to maintain orientation and location (3)				holding down required during subsequent processes to maintain orientation or location (3)			
		easy to align and position during assembly (4)		not easy to align or position during assembly		easy to align and position during assembly (4)		not easy to align or position during assembly	
		no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)
		0	1	2	3	6	7	8	9
0	addition of any part (1) where neither the part itself nor any other part is finally secured immediately; part and associated tool (including hands) can easily reach the desired location	1.5	2.5	2.5	3.5	5.5	6.5	6.5	7.5
1	addition of any part (1) where neither the part itself nor any other part is finally secured immediately; part and associated tool (including hands) cannot easily reach the desired location; due to obstructed-access or restricted vision (2)	4	5	5	6	8	9	9	10
2	addition of any part (1) where neither the part itself nor any other part is finally secured immediately; part and associated tool (including hands) cannot easily reach the desired location; due to obstructed access and restricted vision (2)	5.5	6.5	6.5	7.5	9.5	10.5	10.5	11.5

		no screwing operation or plastic deformation immediately after insertion (snap/press fits, circlips, spire nuts, etc.)		plastic deformation immediately after insertion						screw tightening immediately after insertion (6)	
				plastic bending or torsion			rivetting or similar operation				
				easy to align and position during assembly (4)	not easy to align or position during assembly		easy to align and position during assembly (4)	not easy to align or position during assembly			
		easy to align and position with no resistance to insertion (4)	not easy to align or position during assembly and/or resistance to insertion (5)		no resistance to insertion	resistance to insertion (5)		no resistance to insertion	resistance to insertion (5)	easy to align and position with no torsional resistance (4)	not easy to align or position and/or torsional resistance (5)
		0	1	2	3	4	5	6	7	8	9
3	addition of any part (1) where the part itself and/or other parts are being finally secured immediately; part and associated tool (including hands) can easily reach the desired location and the tool can be operated easily	2	5	4	5	6	7	8	9	6	8
4	addition of any part (1) where the part itself and/or other parts are being finally secured immediately; part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily; due to obstructed access or restricted vision (2)	4.5	7.5	6.5	7.5	8.5	9.5	10.5	11.5	8.5	10.5
5	addition of any part (1) where the part itself and/or other parts are being finally secured immediately; part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily; due to obstructed access and restricted vision (2)	6	9	8	9	10	11	12	13	10	12

		mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				non-mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				non-fastening processes	
		none or localized plastic deformation				metallurgical processes					
							additional material required				
		bending or similar processes	rivetting or similar processes	screw tightening (6) or other processes	snap fit, snap clip, press fit, etc.	no additional material required (e.g. resistance, friction welding, etc.)	soldering processes	weld/braze processes	chemical processes (e.g. adhesive bonding, etc.)	manipulation of parts or sub-assembly (e.g. orienting, fitting or adjustment of part(s), etc.)	other processes (e.g. liquid insertion, etc.)
		0	1	2	3	4	5	6	7	8	9
9	assembly processes where all solid parts are in place	4	7	5	3.5	7	8	12	12	9	12

Figure 3.5: Boothroyd-Dewhurst DFA Manual Insertion Table.

Source: Boothroyd et al. (2002)

3.3.4. Example of Estimating Assembly Time

In this section, a part is taken to show how to utilize the manual handling and insertion time table to obtain total assembly time of a part. First, Obtain size and thickness from the part. Secondly, the orientation of part is taken. Alpha symmetry is rotational symmetry perpendicular to the axis of insertion. Beta Symmetry is the rotational symmetry about the axis of insertion. Lastly, refer to the manual handling table for assembly time estimation.

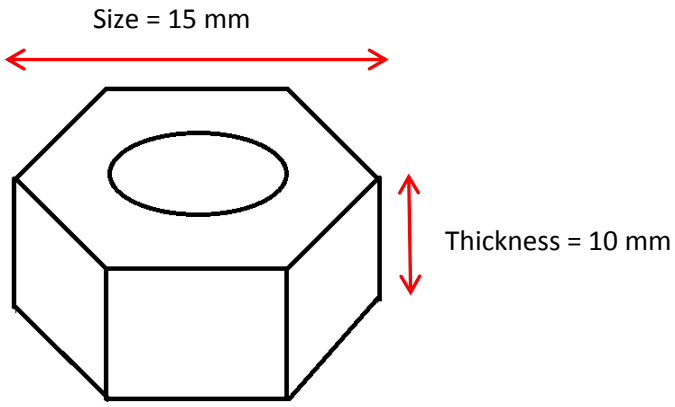


Figure 3.6: An example to estimate assembly time of part.

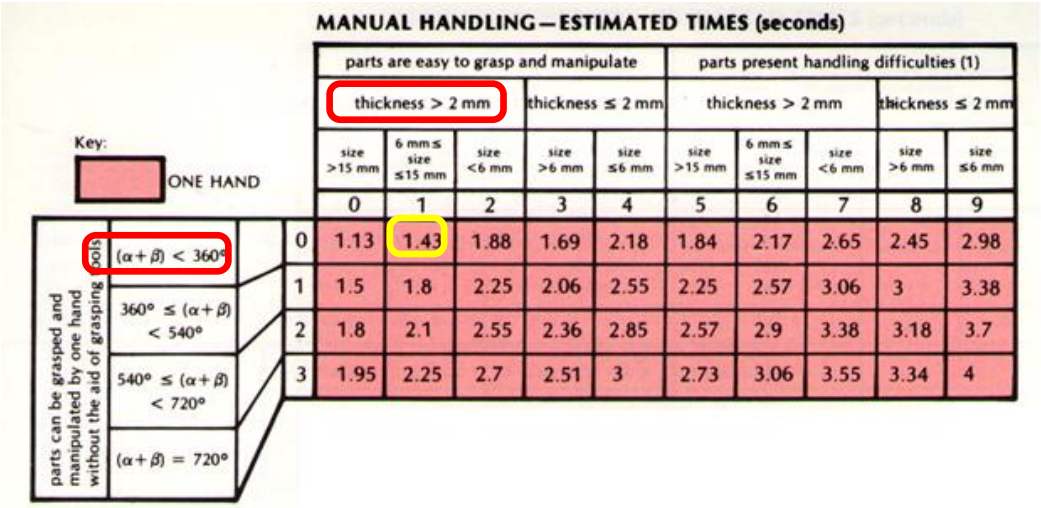
Table 3.2: Dimension and orientation of nut.

Part ID	Part Name	Size (mm)	Thickness (mm)	Alpha, α	Beta, β	α + β
1	Nut	15	10	180	0 °	180 °

Referring to Manual Handling Table:

i. 2 digit manual handling code = 01

ii. Manual handling time = 1.43 seconds.



MANUAL HANDLING—ESTIMATED TIMES (seconds)

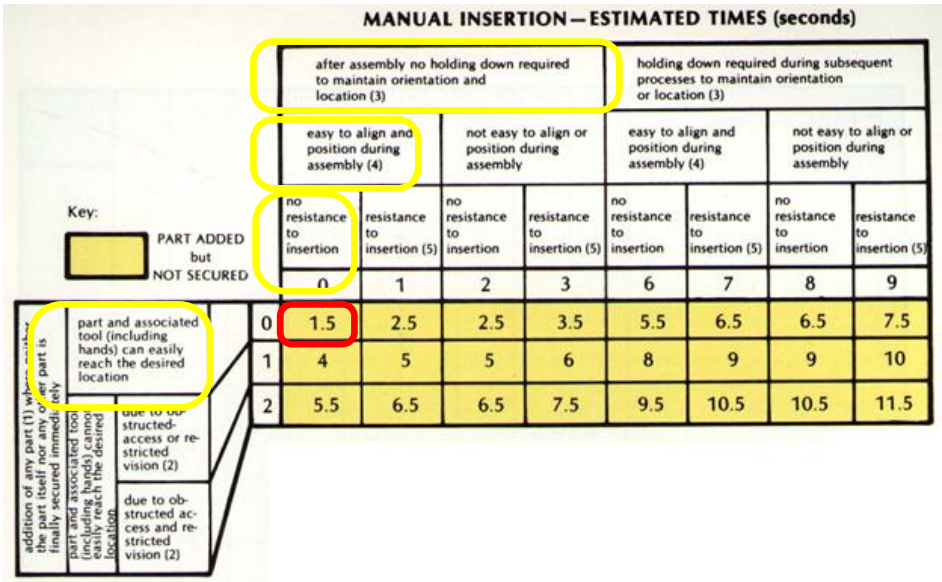
Key: ONE HAND

parts can be grasped and manipulated by one hand without the aid of grasping tools		parts are easy to grasp and manipulate					parts present handling difficulties (1)				
		thickness > 2 mm			thickness ≤ 2 mm		thickness > 2 mm			thickness ≤ 2 mm	
		size >15 mm	6 mm ≤ size ≤15 mm	size <6 mm	size >6 mm	size ≤6 mm	size >15 mm	6 mm ≤ size ≤15 mm	size <6 mm	size >6 mm	size ≤6 mm
		0	1	2	3	4	5	6	7	8	9
$(\alpha+\beta) < 360°$	0	1.13	1.43	1.88	1.69	2.18	1.84	2.17	2.65	2.45	2.98
$360° \leq (\alpha+\beta) < 540°$	1	1.5	1.8	2.25	2.06	2.55	2.25	2.57	3.06	3	3.38
$540° \leq (\alpha+\beta) < 720°$	2	1.8	2.1	2.55	2.36	2.85	2.57	2.9	3.38	3.18	3.7
$(\alpha+\beta) = 720°$	3	1.95	2.25	2.7	2.51	3	2.73	3.06	3.55	3.34	4

Figure 3.7: Example to obtain manual handling code and time

Source: Boothroyd et al. (2002)

In order to obtain the manual insertion time, assume that after assembly, no holding down required, part is easy to align and position and part can easily reach in this location.



MANUAL INSERTION—ESTIMATED TIMES (seconds)

Key: PART ADDED but NOT SECURED

addition of any part (1) where neither the part itself nor any other part is finally secured immediately		after assembly no holding down required to maintain orientation and location (3)				holding down required during subsequent processes to maintain orientation or location (3)			
		easy to align and position during assembly (4)		not easy to align or position during assembly		easy to align and position during assembly (4)		not easy to align or position during assembly	
		no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)
		0	1	2	3	6	7	8	9
part and associated tool (including hands) can easily reach the desired location	0	1.5	2.5	2.5	3.5	5.5	6.5	6.5	7.5
part and associated tool (including hands) cannot easily reach the desired location: due to obstructed access or restricted vision (2)	1	4	5	5	6	8	9	9	10
part and associated tool (including hands) cannot easily reach the desired location: due to obstructed access and restricted vision (2)	2	5.5	6.5	6.5	7.5	9.5	10.5	10.5	11.5

Figure 3.8: Example to obtain manual insertion code and time.

Source: Boothroyd et al. (2002)

Table 3.3: Example of filling the Design for Assembly Manual Worksheet.

Part ID no	**Part Name**	**Number of times the operation is carried out consecutively**	**Two digit Manual Handling Code**	**Manual Handling time per part**	**Two digit Manual insertion code**	**Manual insertion time per part**	**Operation time**	**Theoretical minimum number of parts**
1	Nut	1	01	1.43	00	1.5	2.93	1
						TOTAL:	T_{ma}	N_{min}

Source: (Boothroyd et al., 2002)

3.3.5. Hitachi Assemblability Evaluation Method

The Assemblability Evaluataion Method (AEM) is an effective tool developed by the Hitachi, Ltd to improve design quality for better assembly producibility (Ohashi, et at., 2002). The first step is to determine the assembly sequences of product. Further determine the operation needed to fulfill the assembly sequences. Penalty points are assigned to each part. The Hitachi method uses symbols to represent operations.

i. 100 points to a part for its existence.
ii. Additional points depending on relative difficulty to insert the part.
iii. Additional 15% penalty points for each operation with second operation and beyond.

Asembly time (*AT*) is measured in T-downs. One T-down is the time taken for one downward movement with a part. The summations of the penalty point is the assemblability evaluation score (*E*) used to assess design quality or difficulty of assembly operations. An estimated assembly cost ratio (*K*) is an indication of the assembly cost improvements. It projects the ratio between the assembly costs of the new (modified) design divided by the assembly cost of the initial and/or standard design.

Hitachi consider that an overall score E of 80 is acceptable and overall assembly cost ratio K less than 0.7 is acceptable. The table of penalty points assigned to each operations are as shown from Table 3.7 (a) to (d).

Table 3.4: Manual insertion code and time table. (a) Direction of motion of a part. (b) Joining and processing requirements. (c) Fixture and forming requirements. (d) Other symbols without penalty points.

	Symbol	Penalty Points	Description of Operation
(a)	↓	0	Straight downward
	↑	30	Straight upward
	← →	20	Move horizontally
	↗ ↙	30	Move diagonally up/down
	⊃ ∩	30	Turn like a screw
	R	40	Turn or lift the whole assembly to insert a part
(b)	**Symbol**	**Penalty Points**	**Description of Operation**
	B	20	Bond with adhesive or heat, or lubricate a part
	W	20	Weld
	S	30	Solder
	M	60	Machine a part to join
(c)	**Symbol**	**Penalty Points**	**Description of Operation**
	f	20	Hold a part for next one operation
	F	40	Hold a part for more than one next operations
	G	40	Deform a soft/flexible part
	P	20	(O-ring, gasket) Bend or cut(wires,..)
(d)	**Symbol**	**Penalty Points**	**Description of Operation**
	—	0	Base part for assembly
	|	0	Pipe to keep track of assembly process

Source: Ohashi et al. (2002)

3.3.6. Example of Hitachi AEM Assembly Time Estimation

In this section, an example of Hitachi AEM assembly time estimation is shown.

i. Determine assembly sequences and operations of insertion

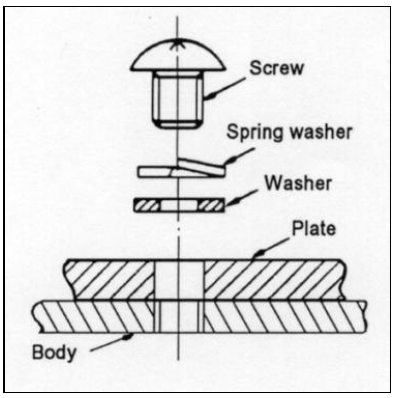


Figure 3.9: An example to estimate assembly time of part (Hitachi AEM)

Source: Ohashi et al. (2002)

Assembly sequences and operations are:

1. Position a body.
2. Bring down a plate.
3. Place and hold washer.
4. Place and hold spring washer.
5. Bring sown and turn a screw.

ii. Part counts are.filled in.

Table 3.5: Hitachi AEM table filled with part counts.

Name	**Count (n)**	**Operation Symbols**
Body	1	
Plate	1	
Washer	1	
Spring Washer	1	
Screw	1	

Source: Ohashi et al. (2002)

iii. Fill table with in operational symbols.

Table 3.6: Hitachi AEM table filled with operation symbols.

Name	**Count (n)**	**Operation Symbols**
Body	1	base
Plate	1	down
Washer	1	down, f
Spring Washer	1	down, f
Screw	1	down, turn

Source: Ohashi et al. (2002)

iv. Assign penalty points to each operation.

Table 3.7: Complete Hitachi AEM table.

Part			Number of Operations (m)	Summation Method			
Name	**Count (n)**	**Operation Symbols**		**Total Penalty (Σ Penalty)**	**M = 100 + Σ Penalty**	**T = M × α + (15 % add op)**	**T × n**
Body	1	base	1	0	100	100	100
Plate	1	down	1	0	100	100	100
Washer	1	down, f	2	20	120	138	138
Spring Washer	1	down, f	2	20	120	138	138
Screw	1	down, turn	2	30	130	150	150
						Σ T × n =	626

Source: Ohashi et al. (2002)

v. Assign penalty points to each operation. Every 100 of points represent 1T↓. Then 626 points represent total assembly time, *E* of 6.26 T↓.

vi. Assembly cost ratio, *K* is calculated using equation (2.4).

$$K = \frac{E}{Es}$$

$$K = \frac{6.26}{6.26}$$

$$K = 1$$

3.3.7. Generate a New Design

The project required to eliminate, modify or redesign the existing product parts. The design analysis data techniques and Boothroyd-Dewhurst DFA Suggestion for Redesign are used to get good design result. By using DFA guidelines and methodology of Boothroyd-Dewhurst DFA, model the 3D modified design by using SolidWorks software. The aim of modification design is to reduce number of part and improve the design efficiency. The new designs are then analyzed by using Algor software to perform stress and strain analysis on the new design.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.0 INTRODUCTION

The presence of every part in a product has its own significant function. However, parts that are less important in terms of contributing to the major operation of the product, can be either eliminated, combined or substitute for the betterment of the product design. At the early stage of design improvement process, the function of each part is to be identified in order to trace for candidates to be combined, upgraded, or even eliminated.

Hence, in this chapter, the following subtopics are discussed with the application of Boothroyd Dewhurst DFA method and Hitachi AEM on the original design as well as the improvement done on the selected bicycle.

i. Analyze the design for assembly efficiency.
ii. Critique the design from an assembly point of view
iii. Redesign the part for improved assembly operations
iv. Quantify the benefits of the redesigned part

4.1 PRODUCT STRUCTURE

The evaluation could not be carry on without further understanding of the detail bicycle structure. Figure 4.1 shows the bicycle product tree of selected bicycle. By dividing product into branches of subassemblies, the assembly evaluation can be done more successfully. The product tree is divided into 6 major parts, which are body, wheel, chain, brake system, handle and seat.

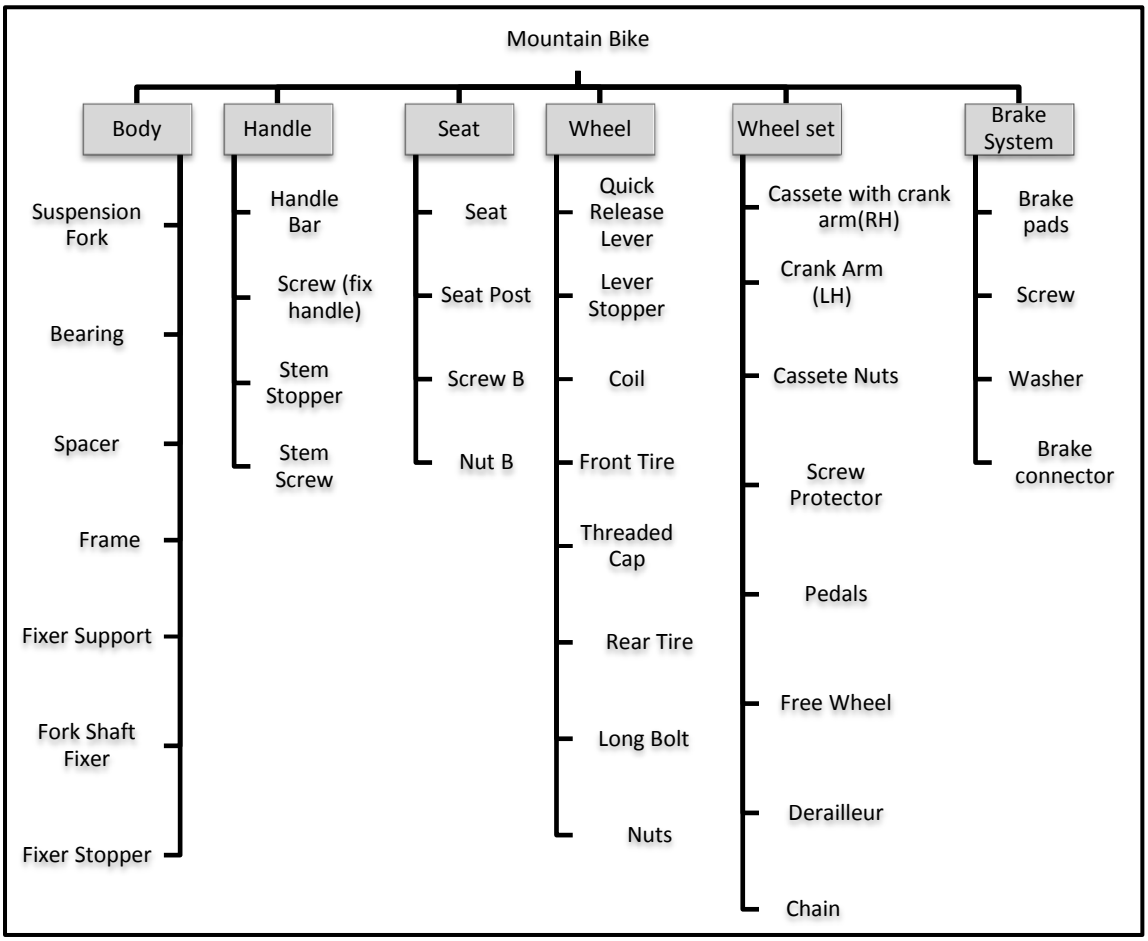


Figure 4.1: Product tree of bicycle existing design.

4.2 PRODUCT DESIGN EVALUATION USING BOOTHROYD DEWHURST DFA METHOD

There are assembly process assumptions to be understood before the evaluation of handling and insertion time is taken. They are:

i. The operator picks up or retrieves the component/sub-assembly from a container and orients it. This is called “part handling”.
ii. Component/sub-assembly is inserted into a simple fixture. This is called “part insertion”.
iii. Whenever possible, the operator uses one hand. The operator never picks up one part in each hand, combines them then places them in the fixture. This obscures individual piece assembly.
iv. Any manipulation of assembled parts or change in direction is defined as reorientation. Any operation to parts already in the fixture is counted as a separate operation. Examples are welding, crimping, etc. The operator uses simple hand tools, no automation.

4.2.1 Parts Quantity and Critiques of Components

The bicycle has been dismantled and analyzed. Referring to Table 4.1, it summarized dimension and orientation of each disassemble part of the bicycle. Referring to Table 4.2, the product has 37 unique parts and in totals 62 numbers of parts. This table also provides functions and critiques of each component in the bicycle.

Table 4.1: Picture, Dimension and Orientation of Components of the Bicycle.

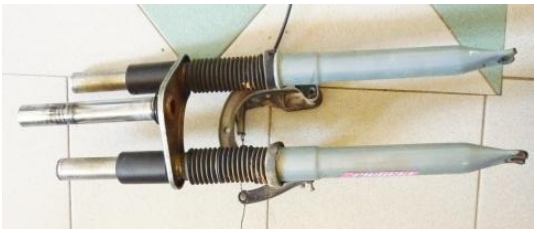
Pictures	**Dimension and orientation**
Fork 	α = 360˚ β = 360˚ Size = 630 mm Thickness = 90 mm
Bearing 	α = 360˚ β = 0˚ Size = 30 mm Thickness = 3 mm
Spacer 	α = 180˚ β = 0˚ Size = 30 mm Thickness = 3 mm
Frame 	α = 360˚ β = 360˚ Size = 800 mm Thickness = 50 mm
Bearing 	α = 360˚ β = 0˚ Size = 30 mm Thickness = 3 mm

Table 4.1: Continued.

Pictures	Dimension and orientation
Triangle Cover Support 	α = 360˚ β = 0˚ Size = 21 mm Thickness = 21 mm
Triangle Cover 	α = 360˚ β = 360˚ Size = 155 mm Thickness = 9 mm
Cover Stopper 	α = 360˚ β = 0˚ Size = 25 mm Thickness = 20 mm
Handle Bar 	α = 360˚ β = 360˚ Size = 570 mm Thickness = 30 mm
Screw (fix handle) 	α = 360˚ β = 0˚ Size = 37 mm Thickness = 15 mm

Table 4.1: Continued.

Pictures	Dimension and orientation
Stem Stopper 	α = 360˚ β = 0˚ Size = 35 mm Thickness = 10 mm
Stem Screw 	α = 360˚ β = 0˚ Size = 30 mm Thickness = 10 mm
Seat 	α = 360˚ β = 360˚ Size = 250 mm Thickness = 80 mm
Seat Post 	α = 360˚ β = 360˚ Size = 250 mm Thickness = 80 mm
Screw B 	α = 360˚ β = 0˚ Size = 60 mm Thickness = 11 mm

Table 4.1: Continued.

Pictures	**Dimension and orientation**
Nut B 	α = 180˚ β = 0˚ Size = 11 mm Thickness = 6 mm
Quick Release Lever 	α = 360˚ β = 0˚ Size = 200 mm Thickness = 16 mm
Lever Stopper 	α = 360˚ β = 0˚ Size = 18 mm Thickness = 8 mm
Coil 	α = 360˚ β = 0˚ Size = 15 mm Thickness = 11 mm
Front Tire 	α = 0˚ β = 360˚ Size = 640 mm Thickness = 110 mm

Table 4.1: Continued.

Pictures	Dimension and orientation
Cap 	α = 360˚ β = 0˚ Size = 20 mm Thickness = 15 mm
Cassette with Crank 	α = 360˚ β = 360˚ Size = 280 mm Thickness = 45 mm
Cassette Nut 	α = 360˚ β = 0˚ Size = 14 mm Thickness = 8 mm
Crank (LH) 	α = 360˚ β = 360˚ Size = 200 mm Thickness = 25 mm
Crank Nut 	α = 360˚ β = 0˚ Size = 14 mm Thickness = 8 mm

Table 4.1: Continued.

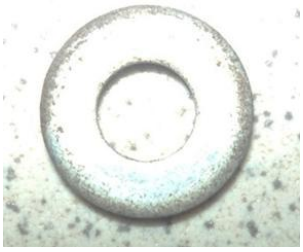
Pictures	**Dimension and orientation**
Screw Protector 	α = 360˚ β = 0˚ Size = 27 mm Thickness = 8 mm
Pedals 	α = 180˚ β = 0˚ Size = 100 mm Thickness = 29 mm
Free Wheel 	α = 360˚ β = 0˚ Size = 110 mm Thickness = 25 mm
Rear Tire 	α = 360˚ β = 0˚ Size = 640 mm Thickness = 200 mm
Washer 	α = 180˚ β = 0˚ Size = 14 mm Thickness = 1.5 mm

Table 4.1: Continued.

Pictures	**Dimension and orientation**
Nut 	α = 180˚ β = 0˚ Size = 14 mm Thickness = 8 mm
Derailleur 	α = 360˚ β = 360˚ Size = 170 mm Thickness = 70 mm
Derailleur Screw 	α = 180˚ β = 0˚ Size = 15 mm Thickness = 15 mm
Chain 	α = 180˚ β = 180˚ Size = 800 mm Thickness = 10 mm
Front Brake 	α = 360˚ β = 360˚ Size = 330 mm Thickness = 20 mm

Table 4.1: Continued.

Pictures	**Dimension and orientation**
Rear Brake 	α = 360˚ β = 360˚ Size = 30 mm Thickness = 20 mm
Washer (brake) 	α = 180˚ β = 0˚ Size = 30 mm Thickness = 2 mm
Screw (brake) 	α = 360˚ β = 0˚ Size = 25 mm Thickness = 13 mm

Table 4.2: Functions and critiques of each component in the bicycle.

Part No	Part Name	Qty	Function	Critique
1	Suspension Fork	1	Mechanical part that integrates bicycle's frame, handlebar and front wheel.	Design of suspension fork need to be revised.
2	Bearing	1	Facilitates rotation by reducing friction.	Standard size.
3	Spacer	1	provides a rotatable interface between the bicycle fork and the head tube of the bicycle frame	Standard size.
4	Frame	1	Provides points of attachment for various components in bicycle.	Standard size.
2a	Bearing	1	Facilitates rotation by reducing friction.	Standard size.
3a	Spacer	1		Standard size.
5	Triangle Cover Support	1	To support the triangle cover.	Can be eliminated.
6	Triangle Cover	1	To fix the two shaft at the suspension fork.	Can be eliminated.
7	Cover Stopper	2	To avoid Triangle cover to slip out.	Can be eliminated.
8	Handle Bar	1	Allows steering and provides a point of attachment for brake controls.	Standard size.
9	Screw (fix handle)	2	To fix handle bar on the suspension fork's stem.	Standard size.
10	Stem Stopper	1	To hold the handle bar at the suspension fork's stem.	Can be combine with stem screw.
11	Stem Screw	1	To fix the handle bar on top.	Standard size.
12	Seat	1	Provides place to be seated when cycling	Standard size.
13	Seat Post	1	A post that the seat is mounted to.	Standard size.
14	Screw B	1	To tighten seat to the seat post.	Standard size.
15	Nut B	2	To tighten seat to the seat post.	Standard size.
12a	Entire Seat Post	1	-	-
A	Up Side Down Bicycle	1	-	-
16	Quick Release Lever	1	A skewer used for releasing wheels with a lever on one end that loosens when the lever is flipped.	Standard size.
17	Lever Stopper	1	To act as base for quick release lever function	Standard size.

Table 4.2: Continued.

Part No	Part Name	Qty	Function	Critique
18	Coil	1	To absorb vibration by tire and provide tolerance for a tighten release lever.	Standard size.
16a	Lever to Front Tire	1	-	-
19	Front Tire	1	Act as a mechanical part that facilitates movement of bicycle.	Standard size.
18a	Coil	1	To absorb vibration by tire and provide tolerance for a tighten release lever.	Standard size.
20	Cap	1	To tighten and fix quick release lever at front tire.	Standard size.
21	Cassette with Crank	1	A group of stacked sprockets on the rear wheel of a bicycle with a rear derailleur.	Standard size.
22	Cassette Nut	1	To tighten cassette.	Standard size.
23	Crank (LH)	1	To act as shaft connected from pedals to cassette.	Standard size.
24	Crank Nut	1	To tighten crank.	Standard size.
25	Screw Protector	2	To protect the crank nut from sand.	Change from screw tightening to snap fit.
26	Pedals	2	A mechanical interface between foot and crank arm.	Standard size.
27	Free Wheel to Rear Tire	1	-	-
28	Rear Tire to Frame	1	-	-
29	Washer (rear tire)	2	Act as spacer to the nut.	Standard size.
30	Nut (rear tire)	2	Tighten the rear tire to bicycle frame.	Standard size.
31	Derailleur	1	An assembly of levers that moves the chain between sprockets on a cassette.	Standard size.
32	Derailleur Screw	1	To fix derailleur to the bicycle frame.	Standard size.
33	Chain	1	A system of interlinking pins, plates and rollers that transmits power from the front sprocket to the rear sprocket.	Standard size.
34	Front Brake	1	Function to add resistance to the tire when need to slow down the bicycle.	Standard size.
35	Rear Brake	1	Function to add resistance to the tire when need to slow down the bicycle.	Standard size.
36	Washer (brake)	4	Act as spacer to the screw.	Standard size.

Table 4.2: Continued.

Part No	Part Name	Qty	Function	Critique
37	Screw (brake)	4	To fix brakes to the bicycle frame.	Standard size.

4.2.2 Assembly Operation Sequence

4.2.2.1 Bicycle Body and Handle

In this section, the assembly's sequences of the bicycle body and handle are explained using flow chart.

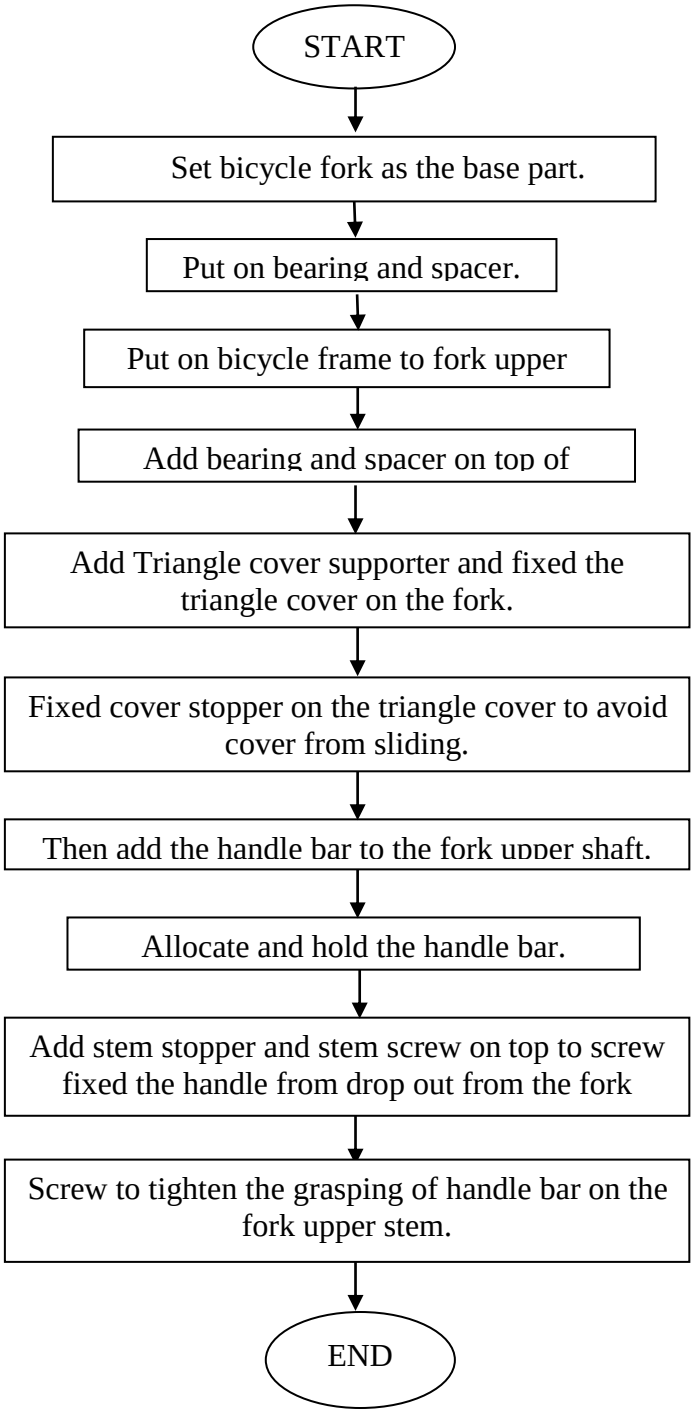


Figure 4.2: Assemble sequence of bicycle body and handle.

4.2.2.2 Seat

In this section, the assembly's sequences of the bicycle seat are explained using flow chart.

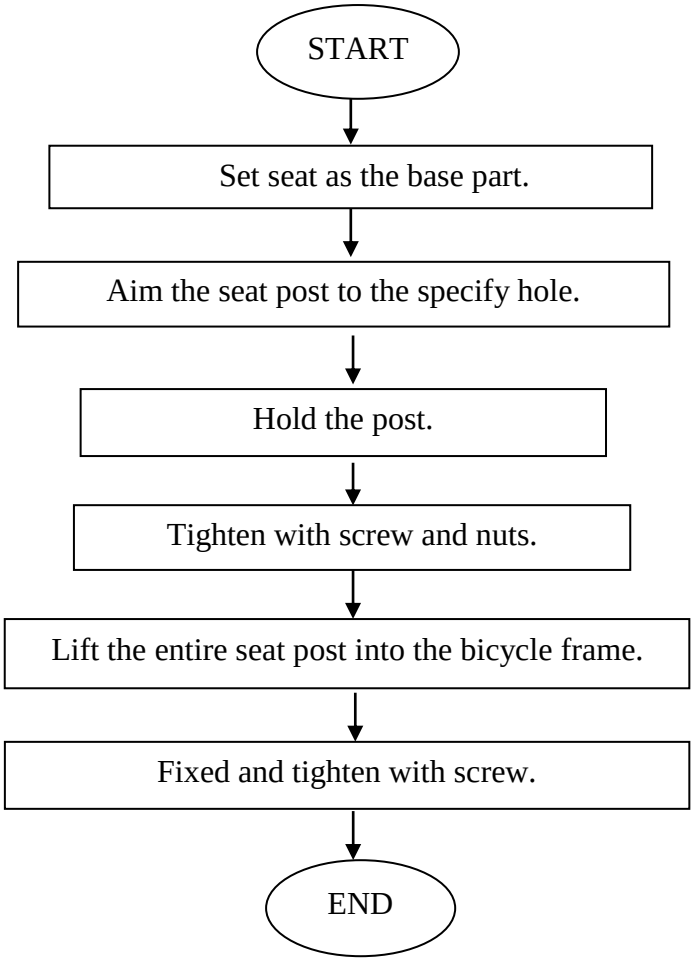


Figure 4.3: Assemble sequence of bicycle seat.

4.2.2.3 Wheel

In this section, the assembly's sequences of the bicycle wheel are explained using flow chart.

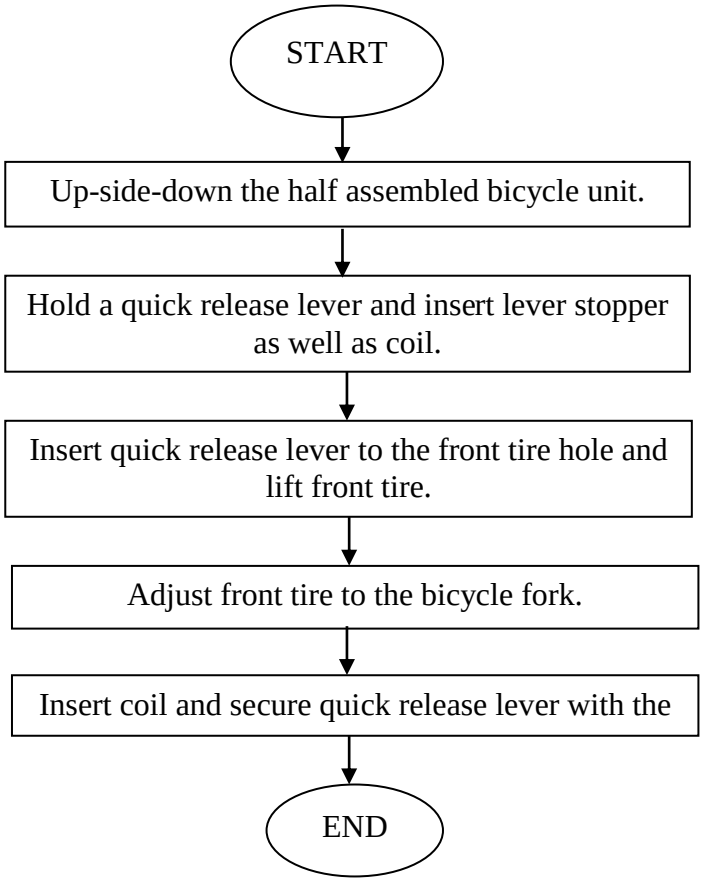


Figure 4.4: Assemble sequence of bicycle wheel.

4.2.2.4 Wheel Set and Brake System

In this section, the assembly's sequences of the bicycle wheel are explained using flow chart.

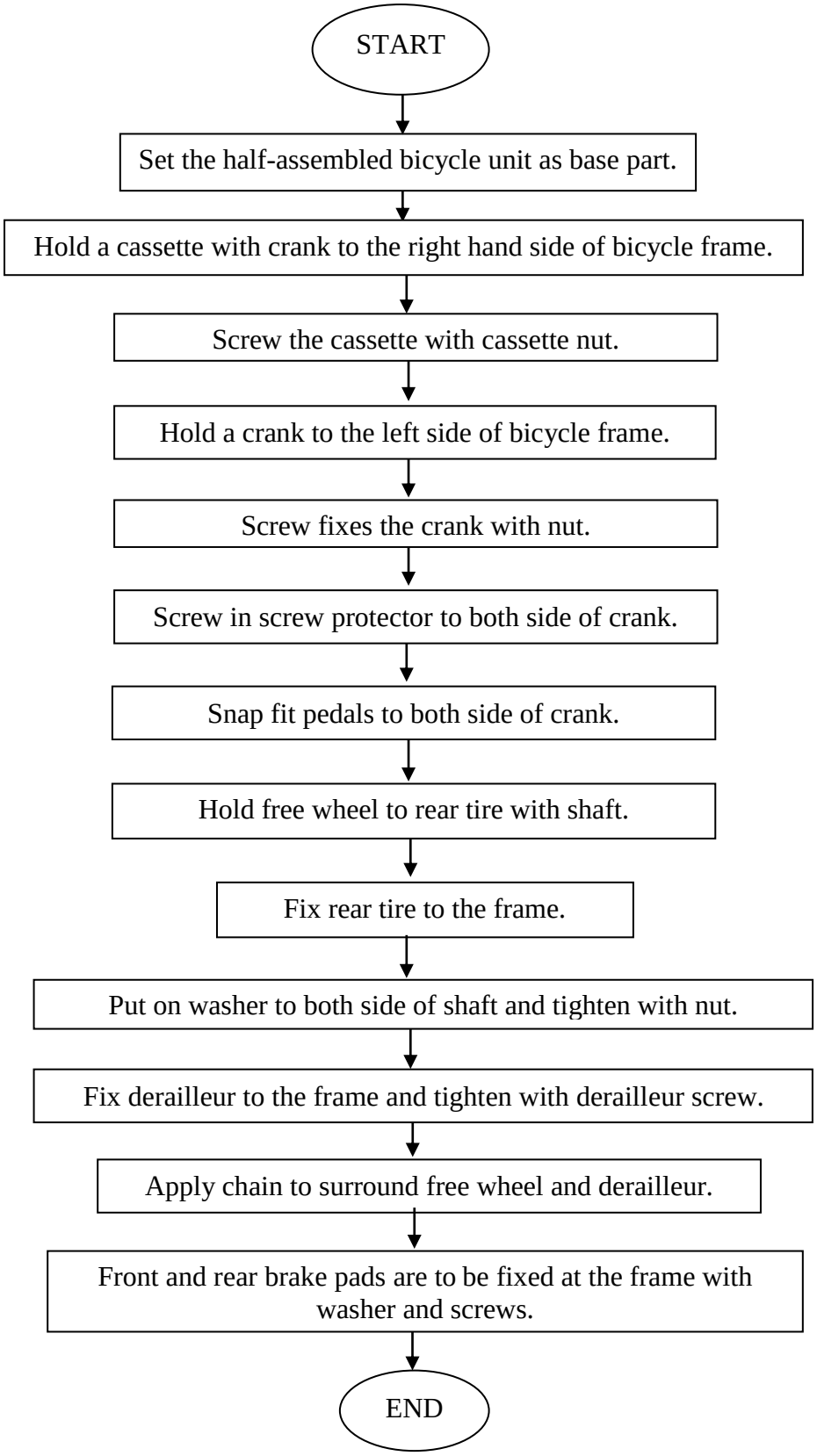


Figure 4.5: Assemble sequence of bicycle wheel set and brake system.

Table 4.3: Design for Assembly (DFA) Worksheet.

Part No	Part Name	No of Operation	Thickness (mm)	Size (mm)	Alpha (α)	Beta (β)	Two-digit Manual Handling Code	Manual Handling Time Per Part (sec)	Two-digit Manual Insertion Code	Manual Insertion Time Per Part (sec)	Operation Time (sec)	Theoretical Minimum Number of Part
1	Fork	1	90	630	360	360	91	3.00	00	1.5	4.50	1
2	Bearing	1	3	30	360	0	10	1.50	00	1.5	3.00	1
3	Spacer	1	3	30	180	0	00	1.13	00	1.5	2.63	1
4	Frame	1	50	800	360	360	91	3.00	00	1.5	4.50	1
2a	Bearing	1	3	30	360	0	10	1.50	00	1.5	3.00	0
3a	Spacer	1	3	30	180	0	00	1.13	00	1.5	2.63	0
5	Triangle Cover Support	1	21	21	360	0	10	1.50	00	1.5	3.00	0
6	Triangle Cover	1	9	155	360	360	30	1.95	06	5.5	7.45	0
7	Cover Stopper	2	20	25	360	0	10	1.50	30	2	7.00	0
8	Handle Bar	1	30	570	360	360	83	5.60	06	5.5	11.1	1
9	Screw (fix handle)	2	15	37	360	0	10	1.50	38	6	15.0	1
10	Stem Stopper	1	10	35	360	0	10	1.50	00	1.5	3.00	1
11	Stem Screw	1	10	30	360	0	10	1.50	38	6	7.50	1
12	Seat	1	80	250	360	360	30	1.95	00	1.5	3.45	1
13	Seat Post	1	30	260	360	0	10	1.50	08	6.5	8.00	1
14	Screw B	1	11	60	360	0	10	1.50	00	1.5	3.00	1
15	Nut B	2	6	11	180	0	01	1.43	38	6	14.86	1
12a	Entire Seat Post	1	180	320	360	360	30	1.95	30	2	3.95	-

Table 4.3: Continued.

Part No	Part Name	No of Operation	Thickness (mm)	Size (mm)	Alpha (α)	Beta (β)	Two-digit Manual Handling Code	Manual Handling Time Per Part (sec)	Two-digit Manual Insertion Code	Manual Insertion Time Per Part (sec)	Operation Time (sec)	Theoretical Minimum Number of Part
A	Up Side Down Bicycle	1	570	800	360	360	91	3	00	1.5	4.5	-
16	Quick Release Lever	1	16	200	360	0	10	1.5	08	6.5	8	1
17	Lever Stopper	1	8	18	360	0	10	1.5	00	1.5	3	1
18	Coil	1	11	15	360	0	10	1.5	00	1.5	3	1
16a	Lever to Front Tire	1	16	200	180	0	00	1.13	06	5.5	6.63	-
19	Front Tire	1	110	640	0	180	90	2	30	2	4	1
18a	Coil	1	11	15	360	0	10	1.5	06	5.5	7	-
20	Cap	1	15	20	360	0	10	1.5	38	6	7.5	1
21	Cassette with Crank	1	45	280	360	360	91	3	06	5.5	8.5	1
22	Cassette Nut	1	8	14	360	0	11	1.8	48	8.5	10.3	1
23	Crank (LH)	1	25	200	360	360	30	1.95	06	5.5	7.45	1
24	Crank Nut	1	8	14	360	0	11	1.8	48	8.5	10.3	1
25	Screw Protector	2	8	27	360	0	10	1.5	38	6	15	0
26	Pedals	2	29	100	180	0	00	1.13	30	2	6.26	1
27	Free Wheel to Rear Tire	1	25	110	360	0	10	1.5	06	5.5	7	1
28	Rear Tire to Frame	1	200	640	0	360	90	2	30	2	4	1
29	Washer (rear tire)	2	1.5	14	180	0	03	1.69	00	1.5	6.38	1
30	Nut (rear tire)	2	8	14	180	0	00	1.3	38	6	14.6	1

Table 4.3: Continued.

Part No	Part Name	No of Operation	Thickness (mm)	Size (mm)	Alpha (α)	Beta (β)	Two-digit Manual Handling Code	Manual Handling Time Per Part (sec)	Two-digit Manual Insertion Code	Manual Insertion Time Per Part (sec)	Operation Time (sec)	Theoretical Minimum Number of Part
31	Derailleur	1	70	170	360	360	30	1.95	08	6.5	8.45	1
32	Derailleur Screw	1	15	15	180	0	00	1.13	39	8	9.13	1
33	Chain	1	10	800	180	180	10	1.5	51	9	10.5	1
34	Front Brake	1	20	330	360	360	83	5.6	19	10	15.6	1
35	Rear Brake	1	20	330	360	360	83	5.6	19	10	15.6	1
36	Washer (brake)	4	2	30	180	0	03	1.69	06	5.5	28.76	1
37	Screw (brake)	4	13	25	360	0	10	1.5	39	8	38	1
		56									**367.03**	33

From the Table 4.3, the analysis shown that the number of different parts of bicycle 37 and the entries which including the repeat parts is 56 parts. Then the total time to assemble the existing mountain bike is 367.03 sec with the total of estimate assembly cost of RM 0.57. The design efficiency is 26.97 % with the labor rate per hour RM 5.625.

4.2.3 Estimation of Assembly Cost for the Original Design

The full potential of DFA is achieved when it is employed with other approaches, complement its capabilities. DFA may be used with design of experiments to determine cost-efficient and high-performance product configurations and manufacturing processes. DFA is an essential part of life cycle costing analyses since it provides early product cost estimates. Hence, it is important to calculate an estimate of assembly cost for the original design and for the improved design. Below are the costing assumptions that have been made to find the design efficiency for the improved bicycle design. The labor cost per month RM 900 is set according to the minimum wage set for private sector employees in the peninsula announce by Datuk Seri Najib Tun Razak (The Star Online, 2012). The costing assumptions are as follows:

i.	Labor Cost per Month	= RM 900
ii.	Week per Month	= 4 weeks
iii.	Working Day per Week	= 5 days
iv.	Working Hour per Day	= 8 hours
v.	Working Hour per Month	= 160 hours
vi.	Labor Cost per Hour	= RM 5.625
vii.	Labor Cost per Second	= RM 0.001563
viii.	Assembly cost per product	= RM 0.001563 x 280.9
		= RM 0. 57

4.2.4 Estimated Design Efficiency for Original Design

The design efficiency of the original bicycle design is calculated.

Design Efficiency for Manual Assembly $= \frac{3 \times NM}{TM} \times 100\ \%$

Where:

NM = Theoretical minimum number of part

TM = Total manually assembly time

From DFA worksheet as shown in Table 4.3;

NM = 33

TM = 367.03

$$\text{Design Efficiency} = \frac{3 \times NM}{TM} \times 100\ \%$$

$$= \frac{3 \times 33}{367.03} \times 100\ \%$$

$$= 26.97\%$$

4.3 REDESIGN PARTS SELECTION AND EVALUATION FOR BOOTHRYOD DEWHURST DFA

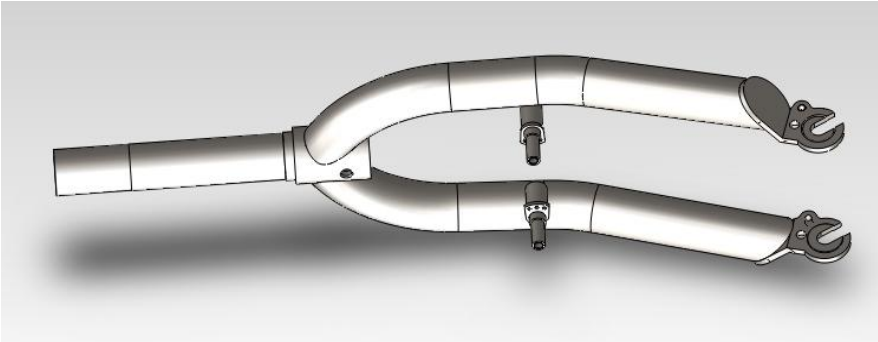
In order to reduce the assembly time for the product, besides eliminating screw and fasteners, new design for components are also generated. The following subtopics showed the modified product for improvement as well as descriptions of the redesign components.

4.3.1 Design Improvements

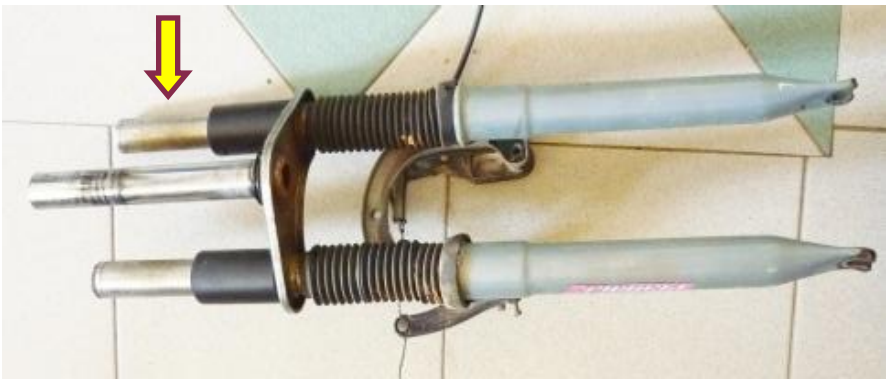
After the analysis from the Boothroyd-Dewhurst DFA table, the assembly guidelines suggest that the assembly of product should be made as simple as possible. The suspension fork is an important component for the bicycle, however the design of suspension fork can be improved so that the by-item used to support the original suspension fork design can be eliminated.

Figure 4.6 shows the original and redesign option for this suspension fork. As in the redesign figure, the main modification is the shaft of the fork. It has been reduce from 3 shafts to only one shaft. From the study of insertion to the bicycle frame, the one shaft design will serve better because it brings simplicity in the product assembly process. With the design, spacers, shaft fixer and fixer support as well as fixer cover is eliminated. This redesign option has reduced complexity of the bicycle fork and will make thus reduce assembly cost.

Figure 4.7 shows the design of combination of the screw and stopper at the handle position. The screw and stopper are initially separated and the operation can actually be combined referring to the assembly guidelines. Figure 4.8 shows the design improvement at the chain system which is the crank screw protector. At this part, the original design of the protector is having thread and should be screwed fix at the insertion operation. Since it is not contributing to the major function of a bicycle, modification is done on it which it change the threaded area to snap fit operation.



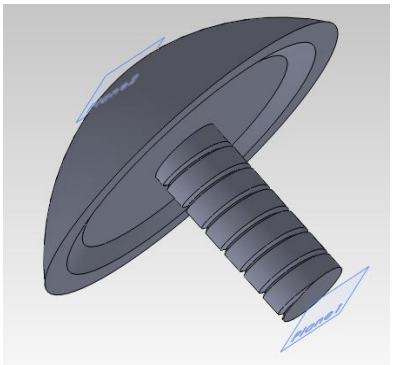
(Redesign)



(Original)

No	Description	Modification
1.	3 shaft at the top of suspension fork. Lead to additional by-item to support the design.	Design a suspension fork with only 1 shaft.
		Eliminate by-items which are shaft fixer, shaft fixer cover and shaft fixer stopper.

Figure 4.6: Suspension fork design improvement.

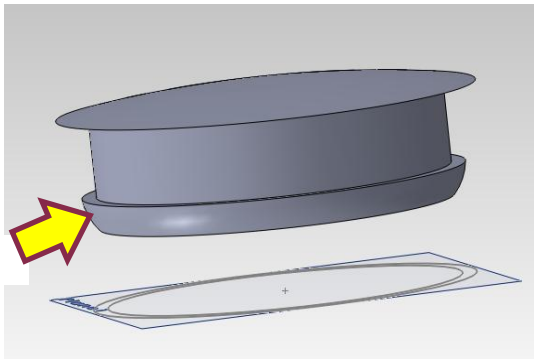


(Redesign)

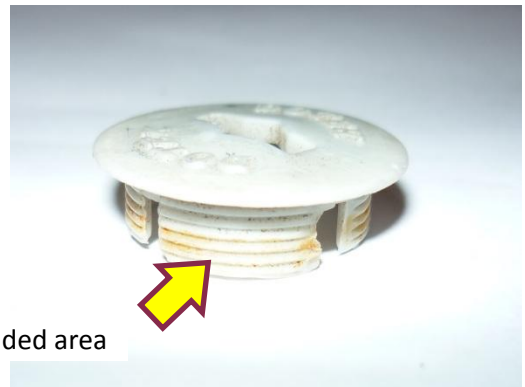
(Original)

No	Description	Modification
1.	Initially needed separated operation for stopper and screw.	Combine the stopper and screw to become one part.
		The redesign screw is now having function as a screw and stopper.

Figure 4.7: Stopper and screw component design improvement.



(Redesign)



(Original)

No	Description	Modification
1.	Consume time to screw fix to cavity.	Change screw function to snap fit.

Figure 4.8: Crank screw protector design improvement.

Table 4.4: Design for Assembly (DFA) Worksheet after Redesign.

Part No	Part Name	No of Operation	Thickness (mm)	Size (mm)	Alpha (α)	Beta (β)	Two-digit Manual Handling Code	Manual Handling Time Per Part (sec)	Two-digit Manual Insertion Code	Manual Insertion Time Per Part (sec)	Operation Time (sec)	Theoretical Minimum Number of Part
1	Fork	1	90	630	360	360	91	3	00	1.5	4.5	1
2	Bearing	1	3	30	360	0	10	1.5	00	1.5	3	1
3	Spacer	1	3	30	180	0	00	1.13	00	1.5	2.63	1
4	Frame	1	50	800	360	360	91	3	00	1.5	4.5	1
2a	Bearing	1	3	30	360	0	10	1.5	00	1.5	3	-
3a	Spacer	1	3	30	180	0	00	1.13	00	1.5	2.63	-
5	Handle Bar	1	30	570	360	360	83	5.6	06	5.5	11.1	1
6	Screw (fix handle)	2	15	37	360	0	10	1.5	38	6	15	1
7	Stem Stopper Screw	1	30	35	360	0	10	1.5	38	6	7.5	1
8	Seat	1	80	250	360	360	30	1.95	00	1.5	3.45	1
9	Seat Post	1	30	260	360	0	10	1.5	08	6.5	8	1
10	Screw B	1	11	60	360	0	10	1.5	00	1.5	3	1
11	Nut B	2	6	11	180	0	01	1.43	38	6	14.86	1
9a	Entire Seat Post	1	180	320	360	360	30	1.95	30	2	3.95	-
A	Up Side Down Bicycle	1	570	800	360	360	91	3	00	1.5	4.5	-
12	Quick Release Lever	1	16	200	360	0	10	1.5	08	6.5	8	1

Table 4.4: Continued.

Part No	Part Name	No of Operation	Thickness (mm)	Size (mm)	Alpha (α)	Beta (β)	Two-digit Manual Handling Code	Manual Handling Time Per Part (sec)	Two-digit Manual Insertion Code	Manual Insertion Time Per Part (sec)	Operation Time (sec)	Theoretical Minimum Number of Part
13	Lever Stopper	1	8	18	360	0	10	1.5	00	1.5	3	1
14	Coil	1	11	15	360	0	10	1.5	00	1.5	3	1
12a	Lever to Front Tire	1	16	200	180	0	00	1.13	06	5.5	6.63	-
15	Front Tire	1	110	640	0	180	90	2	30	2	4	1
14a	Coil	1	11	15	360	0	10	1.5	06	5.5	7	-
16	Cap	1	15	20	360	0	10	1.5	38	6	7.5	1
17	Cassette with Crank	1	45	280	360	360	91	3	06	5.5	8.5	1
18	Cassette Nut	1	8	14	360	0	11	1.8	48	8.5	10.3	1
19	Crank (LH)	1	25	200	360	360	30	1.95	06	5.5	7.45	1
20	Crank Nut	1	8	14	360	0	11	1.8	48	8.5	10.3	1
21	Screw Protector	2	8	27	360	0	10	1.5	30	2	7	1
22	Pedals	2	29	100	180	0	00	1.13	30	2	6.26	1
23	Free Wheel to Rear Tire	1	25	110	360	0	10	1.5	06	5.5	7	1
24	Rear Tire to Frame	1	200	640	0	360	90	2	30	2	4	1
25	Washer (rear tire)	2	1.5	14	180	0	03	1.69	00	1.5	6.38	1
26	Nut (rear tire)	2	8	14	180	0	00	1.3	38	6	14.6	1
27	Derailleur	1	70	170	360	360	30	1.95	08	6.5	8.45	1

Table 4.4: Continued.

Part No	Part Name	No of Operation	Thickness (mm)	Size (mm)	Alpha (α)	Beta (β)	Two-digit Manual Handling Code	Manual Handling Time Per Part (sec)	Two-digit Manual Insertion Code	Manual Insertion Time Per Part (sec)	Operation Time (sec)	Theoretical Minimum Number of Part
28	Derailleur Screw	1	15	15	180	0	00	1.13	39	8	9.13	1
29	Chain	1	10	800	180	180	10	1.5	51	9	10.5	1
30	Front Brake	1	20	330	360	360	83	5.6	19	10	15.6	1
31	Rear Brake	1	20	330	360	360	83	5.6	19	10	15.6	1
32	Washer (brake)	4	2	30	180	0	03	1.69	06	5.5	28.76	1
33	Screw (brake)	4	13	25	360	0	10	1.5	39	8	38	1
		51									**338.58**	33

From the Table 4.4, the analysis shown that the number of different parts of improved bicycle reduces to 33 and the total number of parts including repeated parts is 51. The total assembly time for improved bicycle design is 338.58 sec with the total of estimate assembly cost of RM 0.53. The design efficiency is 29.24 % with the labor rate per hour RM 5.625.

4.3.2 Estimation of Assembly Cost for the Improved Design

The labor cost per month RM 900 is set according to the minimum wage set for private sector employees in the peninsula announce by Datuk Seri Najib Tun Razak (The Star Online, 2012). The cost assumptions for improved bicycle design are as below:

i.	Labor Cost per Month	= RM 900
ii.	Week per Month	= 4 weeks
iii.	Working Day per Week	= 5 days
iv.	Working Hour per Day	= 8 hours
v.	Working Hour per Month	= 160 hours
vi.	Labor Cost per Hour	= RM 5.625
vii.	Labor Cost per Second	= RM 0.001563
viii.	Assembly cost per product	= RM 0.001563 x 338.58
		= RM 0. 53

4.3.3 Estimated Design Efficiency for Improved Design

The design efficiency of the improved bicycle design is calculated in this section.

$$= \frac{3 \times NM}{TM} \times 100\,\%$$

Where:

NM = Theoretical minimum number of part

TM = Total manually assembly time

From DFA worksheet as shown in Table 4.4;

NM = 33

TM = 338.58

$$\text{Design Efficiency} = \frac{3 \times NM}{TM} \times 100\,\%$$

$$= \frac{3 \times 33}{338.58} \times 100\,\%$$

$$= 29.24\%$$

4.4 PRODUCT DESIGN EVALUATION USING HITACHI AEM

The Hitachi AEM analyses the motions and operations, called 'assembly operations', necessary to insert and secure each component of the product. A simple downward motion is considered to be the easiest and fastest assembly operation. Penalty points are given for every motion or operation that differs from, or is in addition to, this simple motion.

This method makes use of assemblability and assembly cost ratio indices to identify the weak points of a design. The procedure begins by entering the motions and operations necessary for assembly onto an AEM form. From drawings (detailed or conceptual) or samples, the analyst completes an AEM form by entering the part names and numbers in the same order that assembly takes place The form is used to compare the assembly processes to the optimum, and given a penalty from the synthetic assembly data.

4.4.1. Original Design Analysis

The assembly sequences of the original rear lamp are shown in the table 4.5. The total assembly time for the original design is 25.07T down and the original design efficiency is 75.78 %.

Table 4.5: Assembly sequences of the original bicycle.

Assembly Process	Operations
Suspension Fork 	Position a main casing as the base.
Bearing 	Bring down bearing to the suspension fork shaft.
Spacer 	Bring down spacer to the suspension fork shaft.
Frame 	Bring down frame to the suspension fork shaft.
Bearing 	Bring down bearing to the suspension fork shaft.

Table 4.5: Continued.

Assembly Process	Operations
Shaft Fixer Support 	Bring down shaft fixer support to the suspension fork shaft.
Shaft Fixer 	Bring down shaft fixer to the suspension fork shaft. Hold the shaft fixer.
Fixer Stopper 	Bring down fixer stopper to avoid movement of shaft fixer.
Handle Bar 	Bring down handle bar to the suspension fork shaft. Hold the handle bar.
Screw (fix handle) 	Position screw horizontally to handle bar. Screw fixed the handle.

Table 4.5: Continued.

Assembly Process	Operations
Stem Stopper 	Bring down stem stopper to top of suspension fork's shaft. Hold the stopper.
Stem Screw 	Bring down stem screw to top of suspension fork's shaft. Screw fixed the stem stopper.
Seat 	Position seat as the base part.
Seat Post 	Bring down seat post. Hold the seat post.
Screw B 	Insert screw B horizontally. Hold screw B.

Table 4.5: Continued.

Assembly Process	Operations
Nut B 	Insert nut B horizontally. Screw fixed nut.
Quick Release Lever 	Hold quick release lever as base.
Lever Stopper 	Bring down lever stopper to quick release lever.
Coil 	Bring down coil to quick release lever.
Front Tire 	Bring down front tire to quick release lever. Hold front tire to quick release lever. Straight upward front tire together with quick release lever. Bring down to the suspension fork.

Table 4.5: Continued.

Assembly Process	Operations
Cap 	Position coil horizontally to quick release lever. Position cap horizontally to quick release lever. Screw fixed cap.
Cassette with Crank 	Position cassette with crank to horizontally frame. Hold cassette with crank.
Cassette Nut 	Position cassette nut horizontally. Screw fixed cassette nut.
Crank (LH) 	Position left hand side crank horizontally frame. Hold crank.
Crank Nut 	Position crank nut horizontally. Screw fixed crank nut.

Table 4.5: Continued.

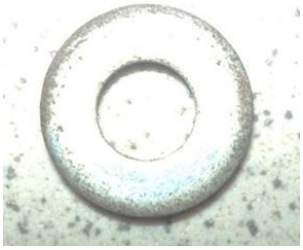
Assembly Process	Operations
Screw Protector 	Position screw protector horizontally. Screw fixed screw protector.
Pedals 	Position pedals horizontally. Snap fit pedals.
Rear Tire 	Rear tire as base part.
Free Wheel 	Bring down free wheel to rear tire. Hold free wheel and rear tire. Bring down to frame. Hold rear tire.
Washer 	Position washer horizontally.

Table 4.5: Continued.

Assembly Process	Operations
Nut 	Position nut horizontally. Screw fixed nut.
Derailleur 	Existing bicycle assembly as base. Position derailleur horizontally to frame. Hold derailleur.
Derailleur Screw 	Position derailleur screw horizontally. Screw fixed derailleur screw.
Chain 	Position chain diagonally to the free wheel and crank wheel.
Front Brake 	Position front brake horizontally. Hold front brake.

Table 4.5: Continued.

Assembly Process	Operations
Rear Brake 	Position rear brake horizontally. Hold rear brake.
Washer (brake) 	Position washer horizontally to brakes. Hold washer.
Screw (brake) 	Position screw horizontally to brake. Screw fixes brake.

Table 4.6: Hitachi AEM evaluation table for original design analysis.

	Part			Number of Operations	Summation Method			
Part No	**Name**	**Count (n)**	**Operations Symbols**	**(m)**	**Total Penalty (Σ Penalty)**	**M = 100 + Σ Penalty**	**T = M*α (+15% add op)**	**T*n**
1	Fork	1	base	1		100	100	100
2	Bearing	1	down	1		100	100	100
3	Spacer	1	down	1		100	100	100
4	Frame	1	down	1		100	100	100
2a	Bearing	1	down	1		100	100	100
3a	Spacer	1	down	1		100	100	100
5	Triangle Cover Support	1	down	1		100	100	100
6	Triangle Cover	1	down, f	2	20	120	138	138
7	Cover Stopper	2	down	1		100	100	200
8	Handle Bar	1	down, f	2	20	120	138	138
9	Screw (fix handle)	2	Horizontal, turn	2	50	150	172.5	345
10	Stem Stopper	1	down	1		100	100	100
11	Stem Screw	1	down, turn	2	30	130	149.5	149.5
12	Seat	1	base	1		100	100	100
13	Seat Post	1	down, f	2	20	120	138	138
14	Screw B	1	Horizontal, f	2	20	120	138	138
15	Nut B	2	Horizontal, turn	2	50	150	172.5	345
12a	Entire Seat Post	1	down	1		100	100	100
A	Up Side Down Bicycle	1	down, R	2	40	140	161	161
16	Quick Release Lever	1	base	1		100	100	100

Table 4.6: Continued.

	Part			Number of Operations	Summation Method			
Part No	Name	Count (n)	Operations Symbols	(m)	Total Penalty (Σ Penalty)	M = 100 + Σ Penalty	T = M*α (+15% add op)	T*n
17	Lever Stopper	1	down	1		100	100	100
18	Coil	1	down	1		100	100	100
16a	Lever to Front Tire	1	down, f	2		100	100	100
19	Front Tire	1	down, R, f	3	60	160	184	184
18a	Coil	1	Horizontal, f	2	40	140	161	161
20	Cap	1	Horizontal, turn	2	50	150	172.5	172.5
21	Cassette with Crank	1	Horizontal, f	2	40	140	161	161
22	Cassette Nut	1	Horizontal, turn	2	50	150	172.5	172.5
23	Crank (LH)	1	Horizontal, f	2	40	140	161	161
24	Crank Nut	1	Horizontal, turn	2	50	150	172.5	172.5
25	Screw Protector	2	Horizontal, turn	2	50	150	172.5	345
26	Pedals	2	Horizontal	1	20	120	138	276
27	Free Wheel to Rear Tire	1	down	1		100	100	100
28	Rear Tire to Frame	1	down, R, f	3	60	160	184	184
29	Washer (rear tire)	2	horizontal	1	20	120	138	276
30	Nut (rear tire)	2	horizontal, turn	2	50	150	172.5	345
31	Derailleur	1	horizontal, f	2	40	140	161	161
32	Derailleur Screw	1	horizontal, turn	2	50	150	172.5	172.5
33	Chain	1	diagonal	1	30	130	149.5	149.5
34	Front Brake	1	horizontal, f	2	40	140	161	161
35	Rear Brake	1	horizontal, f	2	40	140	161	161

Table 4.6: Continued.

	Part			Number of	Summation Method			
Part No	Name	Count	Operations	Operations	Total Penalty (Σ Penalty)	M = 100 + Σ Penalty	T = M*α (+15% add op)	T*n
36	Washer (brake)	4	horizontal, f	2	40	140	161	644
37	Screw (brake)	4	horizontal, turn	2	50	150	172.5	690
A	Up Side Down Bicycle	1	down, R	2	40	140	161	161
	Total	**57**						**8163**

4.4.2. Estimation of Assembly Cost for the Original Design

The cost assumptions for the original bicycle design using Hitachi AEM are calculated as follows:

i. Total score of evaluated design, E = 81.63 T down
ii. Total score of original design = 81.63 T down
iii. Assembly cost ratio using equation (2.4),

$$K = \frac{E}{Es}$$

$$= \frac{81.63}{81.63}$$

$$= 1$$

Note that 1 T down equals to 100 points.

4.4.3. Estimated Design Efficiency for Original Design

The design efficiency of original bicycle design is calculated as below. From Hitachi AEM worksheet;

$$Assembly\ Efficiency = \frac{\Sigma\ part\ count}{\Sigma\ assembly\ time\ in\ T\ down}\ x\ 100\ \%$$

$$= \frac{\Sigma\ n}{\Sigma\ T}\ x\ 100\ \%$$

$$= \frac{57}{81.63}\ x\ 100\ \%$$

$$= 69.82\ \%$$

From the calculation, the assembly efficiency for the original bicycle design is 69.82 %. According to Hitachi, the assembly of a system must exceed 80 % to be justified as a good product design. Hence, improvement should be made for the betterment of assembly efficiency.

4.5 REDESIGN PARTS SELECTION AND EVALUATION FOR HITACHI AEM

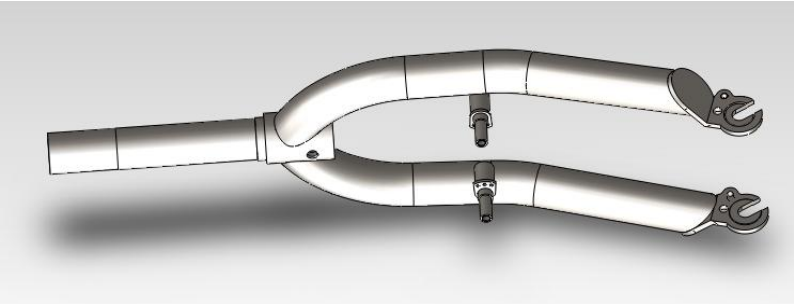
This section discussed the new design proposed after design evaluation using Hitachi AEM method.

4.5.1 Design Improvements

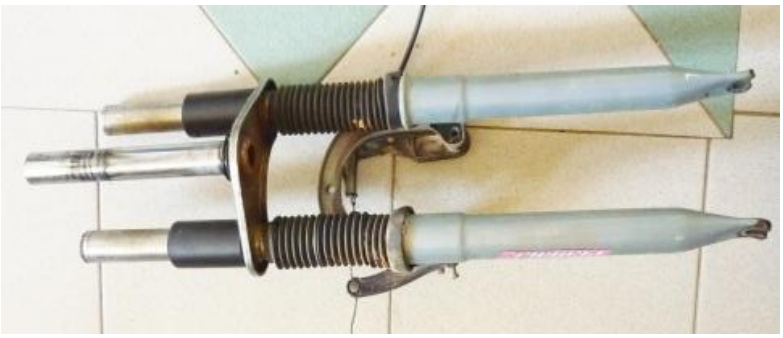
The design improvements done for Hitachi AEM analysis are similar with the Boothroyd-Dewhurst DFA analysis. The suspension fork is an important component for the bicycle, however the design of suspension fork can be improved so that the by-item used to support the original suspension fork design can be eliminated.

Figure 4.9 shows the original and redesign option for this suspension fork. As in the redesign figure, the main modification is the shaft of the fork. It has been reduce from 3 shafts to only one shaft. From the study of insertion to the bicycle frame, the one shaft design will serve better because it brings simplicity in the product assembly process. With the design, spacers, shaft fixer and fixer support as well as fixer cover is eliminated. This redesign option has reduced complexity of the bicycle fork and will make thus reduce assembly cost.

Figure 4.10 shows the design of combination of the screw and stopper at the handle position. The screw and stopper are initially separated and the operation can actually be combined referring to the assembly guidelines. Figure 4.11 shows the design improvement at the chain system which is the crank screw protector. At this part, the original design of the protector is having thread and should be screwed fix at the insertion operation. Since it is not contributing to the major function of a bicycle, modification is done on it which it change the threaded area to snap fit operation.



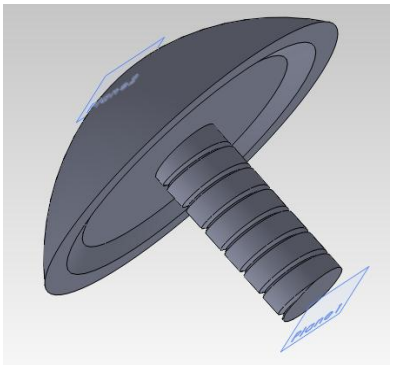
(Redesign)



(Original)

No	Description	Modification
1.	3 shaft at the top of suspension fork. Lead to additional by-item to support the design.	Design a suspension fork with only 1 shaft.
		Eliminate by-items which are shaft fixer, shaft fixer cover and shaft fixer stopper.

Figure 4.9: Suspension fork design improvement (Hitachi AEM).

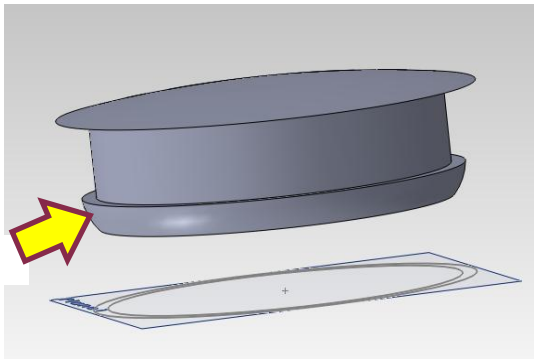


(Redesign)

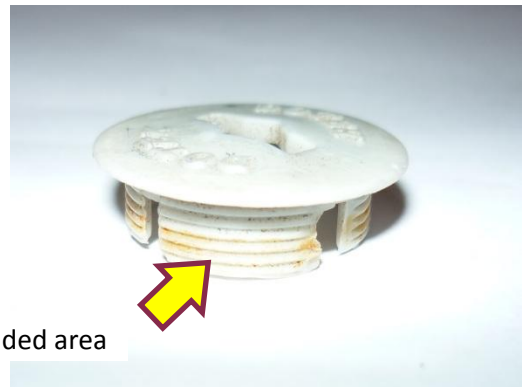
(Original)

No	Description	Modification
1.	Initially needed separated operation for stopper and screw.	Combine the stopper and screw to become one part.
		The redesign screw is now having function as a screw and stopper.

Figure 4.10: Stopper and Screw design improvement (Hitachi AEM).



(Redesign)



(Original)

No	Description	Modification
1.	Consume time to screw fix to cavity.	Change screw function to snap fit.

Figure 4.11: Crank screw cover design improvement (Hitachi AEM).

Table 4.7: Hitachi AEM evaluation table for improved design analysis.

	Part			Number of Operations	Summation Method			
Part No	Name	Count (n)	Operations Symbols	(m)	Total Penalty (Σ Penalty)	M = 100 + Σ Penalty	T = M*α (+15% add op)	T*n
1	Fork	1	base	1		100	100	100
2	Bearing	1	down	1		100	100	100
3	Spacer	1	down	1		100	100	100
4	Frame	1	down	1		100	100	100
2a	Bearing	1	down	1		100	100	100
3a	Spacer	1	down	1		100	100	100
5	Handle Bar	1	down, f	2	20	120	138	138
6	Screw (fix handle)	2	Horizontal, turn	2	50	150	172.5	345
7	Stem Screw	1	down, turn	2	30	130	149.5	149.5
8	Seat	1	base	1		100	100	100
9	Seat Post	1	down, f	2	20	120	138	138
10	Screw B	1	Horizontal, f	2	20	120	138	138
11	Nut B	2	Horizontal, turn	2	50	150	172.5	345
9a	Entire Seat Post	1	down	1		100	100	100
A	Up Side Down Bicycle	1	down, R	2	40	140	161	161
12	Quick Release Lever	1	base	1		100	100	100
13	Lever Stopper	1	down	1		100	100	100
14	Coil	1	down	1		100	100	100
12a	Lever to Front Tire	1	down, f	2		100	100	100
15	Front Tire	1	down, R, f	3	60	160	184	184

Table 4.7: Continued.

	Part			Number of Operations	Summation Method			
Part No	**Name**	**Count (n)**	**Operations Symbols**	**(m)**	**Total Penalty (Σ Penalty)**	**M = 100 + Σ Penalty**	**T = M*α (+15% add op)**	**T*n**
14a	Coil	1	Horizontal, f	2	40	140	161	161
16	Cap	1	Horizontal, turn	2	50	150	172.5	172.5
17	Cassette with Crank	1	Horizontal, f	2	40	140	161	161
18	Cassette Nut	1	Horizontal, turn	2	50	150	172.5	172.5
19	Crank (LH)	1	Horizontal, f	2	40	140	161	161
20	Crank Nut	1	Horizontal, turn	2	50	150	172.5	172.5
21	Screw Protector	2	Horizontal	1	20	120	138	276
22	Pedals	2	Horizontal	1	20	120	138	276
23	Free Wheel to Rear Tire	1	down	1		100	100	100
24	Rear Tire to Frame	1	down, R, f	3	60	160	184	184
25	Washer (rear tire)	2	horizontal	1	20	120	138	276
26	Nut (rear tire)	2	horizontal, turn	2	50	150	172.5	345
27	Derailleur	1	horizontal, f	2	40	140	161	161
28	Derailleur Screw	1	horizontal, turn	2	50	150	172.5	172.5
29	Chain	1	diagonal	1	30	130	149.5	149.5
30	Front Brake	1	horizontal, f	2	40	140	161	161
31	Rear Brake	1	horizontal, f	2	40	140	161	161
32	Washer (brake)	4	horizontal, f	2	40	140	161	644
33	Screw (brake)	4	horizontal, turn	2	50	150	172.5	690
A	Up Side Down Bicycle	1	down, R	2	40	140	161	161
	Total	**52**						**7556**

4.5.2 Estimation of Assembly Cost Ratio for Improved Design

The cost assumptions of improved bicycle design using Hitachi AEM are discussed in this section.

i. Total score of evaluated design, E = 75.56 T down
ii. Total score of original design = 81.63 T down
iii. Assembly cost ratio,

$$K = \frac{E}{Es}$$

$$= \frac{75.56}{81.63}$$

$$= 0.92$$

4.5.3 Estimated Design Efficiency for Improved Design

The design efficiency for improves bicycle design using Hitachi AEM is shown in this section.

$$Assembly\ Efficiency = \frac{\Sigma\ part\ count}{\Sigma\ assembly\ time\ in\ T\ down}\ x\ 100\%$$

$$= \frac{\Sigma\ n}{\Sigma\ T}\ x\ 100\ \%$$

$$= \frac{52}{75.56}\ x\ 100\ \%$$

$$= 68.82\ \%$$

From the calculation, the assembly efficiency for the improve bicycle design is 68.82 %. According to Hitachi, the assembly of a system must exceed 80 % to be justified as a good product design. Hence, the improvement done has not met the requirement of a good design criterion.

4.6 COMPARISON OF DFA METHODS

Table 4.8: Table of comparison of Boothroyd-Dewhurst DFA.

Descriptions	Original Design	Improved Design
Assembly Time (S)	367.03	338.58
Assembly Cost (RM)	0.57	0.53
Design Efficiency (%)	26.97	29.24

Table 4.9: Table of comparison of Hitachi AEM.

Descriptions	Original Design	Improved Design
Assembly Time (T down)	81.63	75.56
Assembly Cost Ratio	1	0.92
Assembly Efficiency (%)	69.83	68.82

From Table 4.8, it shows the quantified results compared between original and improved design using Boothroyd-Dewhurst DFA method. The assembly time has reduced from 367.03 sec to 338.58 sec. This reduction lead to assembly cost reduction, which was from RM 0.57 per product to RM 0.53 per product. The design improvements have successfully increased the design efficiency of bicycle from 26.97 % to 29.24 %.

For Hitachi AEM evaluation, from the table, the assembly cost ratio is reduced to 0.92. However, the improvements must reduce 30 % of the original cost which is assembly cost ratio equal or lesser than 0.7. For the assembly efficiency, the improved product design has a lower efficiency than the original design. This shows that the improved design still have rooms of improvements. From that, a conclusion can be made that the Hitachi AEM method considers both cost and quality as equally important. The low cost design is not necessarily the best (Mital. et. al., 2008).

4.7 ALGOR SIMULATION ANALYSIS

The parts that have been redesign need to be analyze on the quality of product. Only the bicycle fork and the combination of handle stopper and screw need to be analyze. The crank's covers need no justification because it has no external force acting to it when load is applied to the bicycle. The brief discussion about the assumptions made in the simulation using Algor finite element analysis software.

4.7.1 Assumptions

There are few assumptions made in order to perform the Algor simulation analysis for bicycle new designed components. They are:

i. The material selection for bicycle fork is steel (AISI 4130).
ii. The maximum force supply to the fork is 1500 N.
iii. The maximum force acted supply to the combination of stopper and screw is 981 N.
iv. The material of suspension fork and the combination of screw with stopper are same, which is the steel AISI 4130.

4.7.2 Specification of Material

The material selected is Steel AISI 4130. It is bar austenitized at temperature 1575 Fahrenheit, water quenched, and tempered at temperature 800 Fahrenheit for 1 hour.

Table 4.10: Material properties of Steel (AISI 4130).

Material Properties Of AISI 4130	Values
Mass density ($Ns^{-2}/mm/mm^3$)	7.823×10^{-9}
Modulus of Elasticity (N/mm^2)	206842.72
Poisson's Ratio	0.3
Thermal Coefficient of Expansion ($1/^oC$)	0.0000135
Shear Modulus of Elasticity (N/mm^2)	79565.5

Source: Autodesk Algor Simulation Professional (2011)

4.7.3 Algor Simulation Analysis for Bicycle Fork

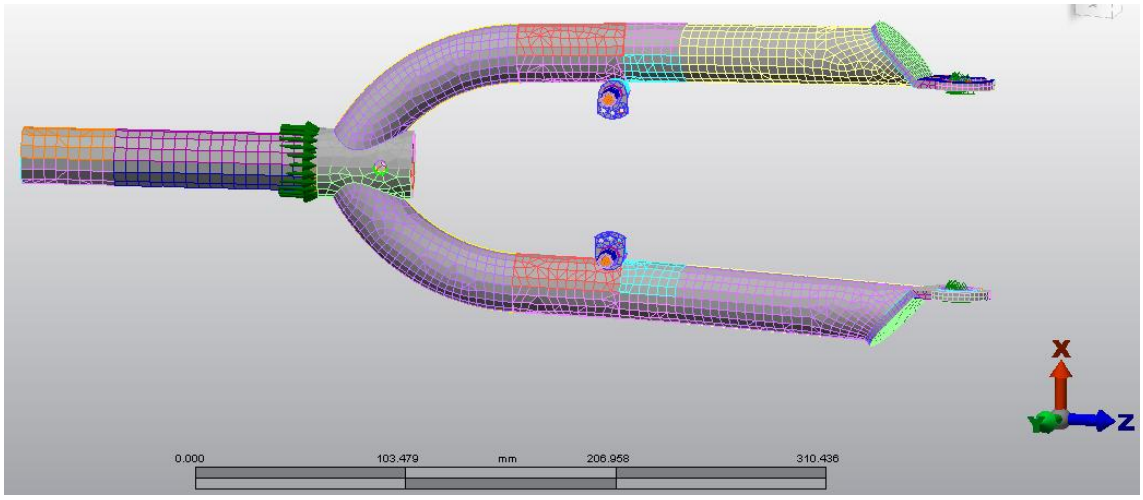


Figure 4.12: Compression force applied on redesign suspension fork.

Source: Autodesk Algor Simulation Professional 2011

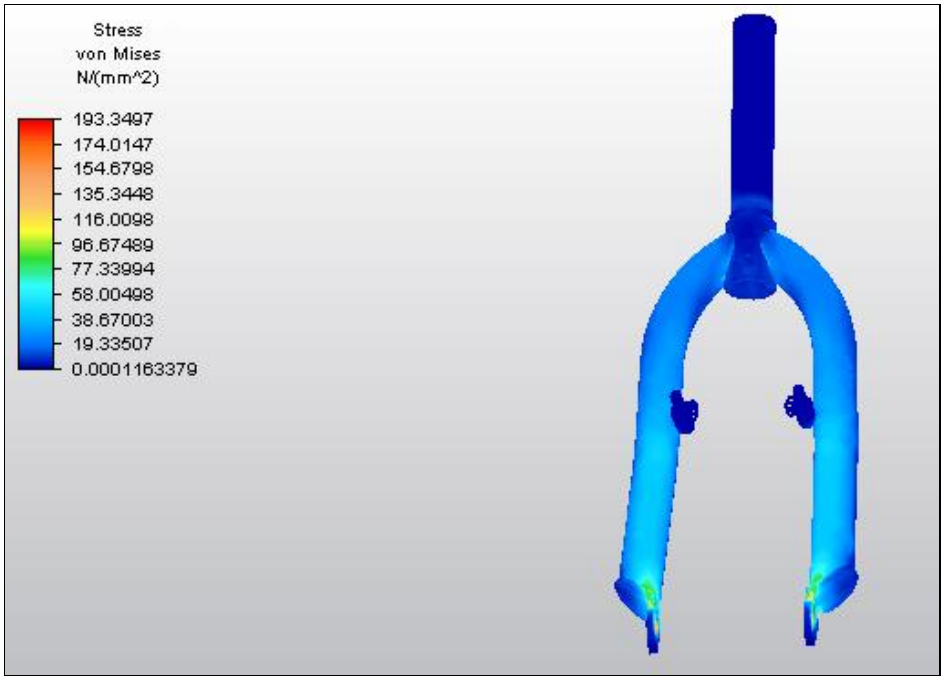


Figure 4.13: Weak points of redesign suspension fork.

Source: Autodesk Algor Simulation Professional (2011)

From the material properties of AISI 4130 steel, modulus of elasticity or more commonly known as yield strength is approximate 200 kN/mm^2. This means that when the von Mises stress reaches beyond 200 kN/mm^2, the material in suspension fork will permanently deforms, which means it will never turned back to its original shape after the deflection.

Figure 4.12 showed direction of compression force applied on the improved suspension fork. The compression force acted on it include the weight of the bicycle itself and as well as the cyclist. Note that the compression force acted on the bicycle is of static load. There is no accepted "standard load set" for designers to work with (Peterson. and Londry, 1986). Hence, the load applied towards the improved suspension fork for this is finite element analysis is 1500 N. After analysis performs on the suspension fork, the result can be seen in Figure 4.13. It shows that the weak points of suspension fork focus on the contact area of front tire bolts with the fork clamp. When 1500 N of force applied towards the bicycle fork, the maximum von Mises stress is 193.35 N/mm^2. From the material properties of AISI 4130 steel, the maximum yield strength of it is 200 kN/mm^2, hence, the improve design suspension fork can withstand a lot more load beyond 1500 N without worrying it will fail.

4.7.4 Algor Simulation Analysis for Combined Handle Stopper and Screw

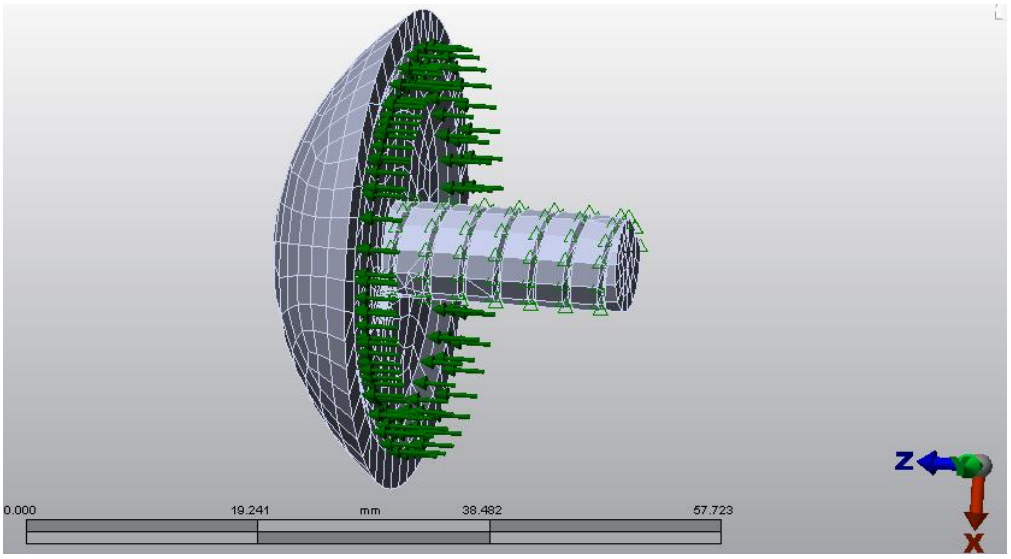


Figure 4.14: Compression force applied on combined handle stopper and screw.

Source: Autodesk Algor Simulation Professional 2011

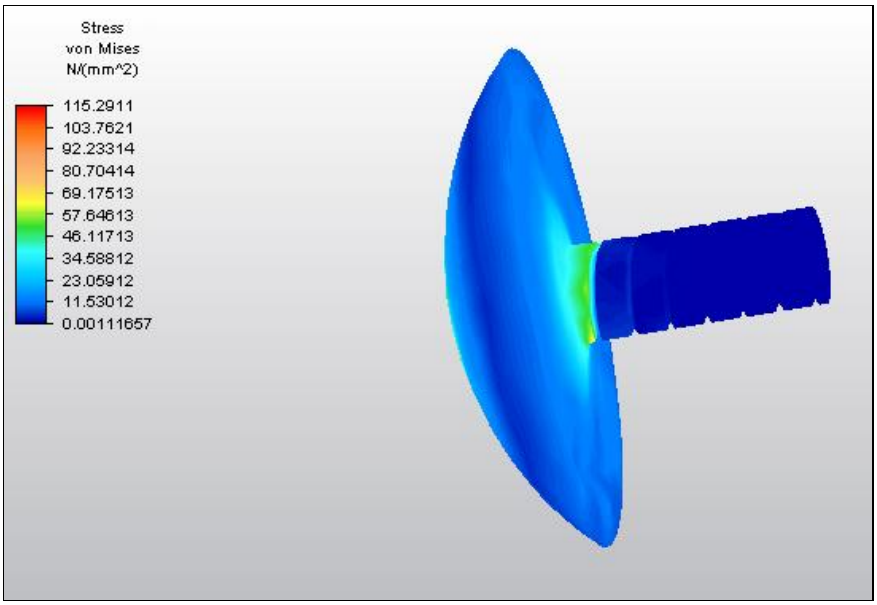


Figure 4.15: Weak points of combined handle stopper and screw.

Source: Autodesk Algor Simulation Professional 2011

This part analyzes the improved design of combination of stopper and screw at handle stem position. From previous session we know that the material properties of AISI 4130 steel have modulus of elasticity approximate 200 kN/mm^2. Figure 4.14 showed direction of compression force applied on the combined stopper and screw. The compression force acted on it includes the reaction force acted towards the suspension fork by weight of cyclist. A 150 lb or approximate 70 kg cyclist is used as the average cyclist weight by Peterson and Londry (1986) for experimenting bicycle frame analysis . Note that the compression force acted on the candidate is of static load.

In order to test the durability of the combined stopper and screw, 100 kg is used instead of 70 kg. After analysis performs on the candidate, the result can be seen in Figure 4.15. It shows that the weak points of suspension fork focus on the edge of screw connected to the stopper. Maximum von Mises stress is 115.3 N/mm^2. From the material properties of AISI 4130 steel, the maximum yield strength of AISI 4130 steel is 200 kN/mm^2, hence, the combination of screw and stopper can withstand a lot more load before reaches the breaking stress.

4.8 SUMMARY

This chapter discussed the result and analysis of the project which based on applying method and Hitachi AEM in optimizing bicycle design. For Boothroyd-Dewhurst DFA, the evaluation results show the design efficiency increased from 26.97 % to 29.24 % after number of parts were eliminated from 37 parts to 33 parts. The design evaluation for Hitachi AEM shows slight decrement in assembly efficiency which is 69.83 % to 68.82 % although there are 4 parts been eliminated. The decrease in assembly efficiency is due to the Hitachi AEM focuses on motion of parts. The operations of parts should be reduced more significantly to get assembly efficiency improve.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

This chapter summarized the conclusions and recommendations for the set of project objectives based on Boothroyd Dewhurst DFA and Hitachi AEM DFA analysis. The comprehensive analysis by using DFA had suggested elimination of parts such as two spacers at the suspension shaft, the fixer cover, and two of the fixer stoppers. For Boothroyd-Dewhurst DFA method, the DFA evaluation on improved design efficiency had shown increases to 29.24 % compared to existing which is 26.97 %. However, for Hitachi AEM, the assembly efficiency of the existing design of bicycle is 69.83 %, whereas after design improvements, the design efficiency of bicycle is 68.82 %.

In terms of cost reduction, by using Boothroyd-Dewhurst DFA method, the assembly cost for improved design is RM 0.53 compared to previous design RM 0.57, RM 0.04 of cost is reduce per product. The assembly cost ratio of bicycle for evaluation using Hitachi AEM is 1 for the original design and 0.92 for the improved design. Therefore, the evaluation result for Hitachi AEM is considered not significant due to the reduction of cost ratio must be higher than 30 % to consider as a successful design improvements. However, for Boothroyd-Dewhurst DFA method, the design improvements done are considered significant.

5.2 RECOMMENDATIONS FOR FUTURE WORKS

The overall studies can be held more precisely by using Boothyod-Dewhurst DFA software. DFA is used by engineers to reduce the assembly cost of a product by consolidating parts into elegant and multifunctional designs. The DFA complements Design for Manufacture (DFM). DFM software then allows the design engineer quickly to judge the cost of producing the new design and to compare it with the cost of producing the original assembly. Used together, DFM and DFA software gives engineers an early cost profile of product designs, providing a basis for planning and decision making. Such analyses, when performed at the earliest stages of concept design, have the potential to greatly influence manufacturing and other life-cycle costs before the costs are locked in.

Secondly, the evaluation and new design for selected product are only based on Design for Assembly (DFA) methods and the full potential of DFA is achieved when it is employed with other tools and approaches to compensate its limitations or complement its capabilities. Besides the establishing of handling and insertion cost to justify practicability of DFA, one can also uses DFA with quality function deployment (QFD) techniques to determine the feasibility of achieving customer requirements for a new product. On the other hand, besides handling, insertion and operation issues, there are other crucial factors that also give impact on the total cost of product are neglected such as the manufacturing of new design parts inclusive the material cost.

Thirdly, this DFA study should be carried out together with the design team of a specific company. When carry out the improvement for product design, it is very crucial that one realized that the improvements done on a product selected are contributing to the company's production as well as aiding the company to reduce investment cost. The timing for implementing the DFMA evaluation for a product is best done before the launching of a new design product. This helped the researcher to justify his or her work is worthwhile. By then both the company and the researcher benefited and hard work contributed will worth and achieve win-win situation.

Next, when pursuing DFA research, the suggestion of having more than one person in a group is encouraged. This is due to the best results are achieved if the performing team consists of about four to six people with backgrounds in design, production, quality, purchasing, logistics and marketing (Prologia, 2009).

Last but not the least, the product design can be model using other CAD software like Pro/ENGINEER and AutoCAD other than Solidworks. Same goes to the extensive analysis like stress-strain distribution and Failure Mode Analysis by using Computer Aided Engineering (CAE) software. Software like FEMPRO, NASTRAN and PATRAN are suggested beside usage of Algor depending on the product being evaluated.

REFERENCES

Ahmad, Z. A. and Sipalan, J. 2012. Lowest salary set at RM900. The Star Online. 1st May.

Barnes, G. and Krizek, K. 2005. Estimating Bicycling Demand.

Belay, A. M. 2009. Design for manufacturability and concurrent engineering for product development. World Academy of Science, Engineering and Technology, 49: 240-246

Boothroyd, G., Dewhurst, P. and Knight, W. 2002. Product design for manufacture and assembly. 2nd ed. New York: Marcel Dekker, Inc.

Chang, T.C., Wysk, H.P. and Wang. 1998. Computer-aided manufacturing. 2nd ed. New York: Prentice Hall.

Dewhurst, N.P. 2005. The true cost of overseas manufacture. Slide. Bloomingdale, IL: Boothroyd Dewhurst, Inc.

Estorilio C. and Simião C.M. 2006. Cost reduction of a diesel engine using the DFMA method. Product Management & Development. 4(2): 95-103.

Ghazalli, Z., Noor,M.M and Hamedon, Z. 2008. Development of conceptual technique by using integrated approaches. Regional Conference on Vehicle Engineering and Technology, pp. 12-19.

Ismail A.R., Manap A.H.A.A., Wahab D.A., Zulkifli R., Makhtar N.K. and Sopian K. 2009. Concurrent engineering approach in designing pressure vessel. European Journal Of Scientific Research. 30(2): 245-252.

Isaacson, W. 2011. Steve jobs. New York: Simon & Schuster.

Lin, J. J. Y. 2008. Research on collaborative concept design integrating the application of Virtual Reality and DFMA. Computer Supported Cooperative Work in Design, pp. 727-732.

Krumenauer , F.Z., Matayoshi, C.T., da Silva, I.B., Filho, M.S., Batalha, G.F. 2008. Concurrent engineering and DFMA approaches on the development of automotive panels and doors. Journal of Achievements in Materials and Manufacturing Engineering. 31(2): 690-698.

Massachusetts Statewide Bicycle Transportation Plan: Current and Future Bicycle Demand. 1990

Mital, A., Desai, A., Subramanian, A., and Mital, A. 2008. Product development: a structured approach to design and manufacture. UK: Elsevier.

Mohamed, M. 2010. Product design improvement through integration of Theory Of Inventive Problem Solving (TRIZ) and Design for Manufacture And Assembly (DFMA). Master Thesis. Universiti Teknologi Malaysia, Malaysia.

Nawi, M. H. 2010. Cost reduction study of automotive part using DFA method: rear lamp. Degree thesis. Universiti Malaysia Pahang, Malaysia.

Nicholas D. 2005. *The true cost of overseas manufacture*. Slide. Bloomingdale: Boothroyd Dewhurst, Inc.

Osiris, C. J., Buiarskey Kovalchukb J. P., and Antonio, B. 2009. The white goods part designed based on DFM/DFA concepts in a concurrent engineering environment. *Brazilian Journal of Operations & Production Management*. **6**(2): 75-100.

Ohashi, T., Iwata, M., Arimoto, S., and Miyakawa, S. 2002. Extended Assemblability Evaluation Method (AEM). *JSME International Journal Series C*. **45** (2): 567 – 574.

Peterson L. A. and Londry K.J. 1986. Finite-Element Structural Analysis: A New Tool for Bicycle Frame Design. *Bicycling Magazine's Newsletter for the Technical Enthusiast*. **5**(2).

Robert B. S., Daniel A. M., Varghese J. K. 2003. A product architecture-based conceptual DFA technique. *Design Studies*. **25**(3): 301–325.

Rozali. A. 2010. Product design improvement through Design For Manufacture And Assembly (DFMA) and Theory of InventiveProblem Solving (TRIZ). Master Thesis. Universiti Teknologi Malaysia, Malaysia.

Wang, B. 1997. *Integrated product, process and enterprise design.* Engineering Series. London: Chapman & Hall.

Wu, T. and O'Grady, P. 1999. A concurrent engineering approach to design for assembly. *Concurrent Engineering.* **7**(3): 231-243.

Zubir, B. 2007. Assemblability Design Efficiency (ADE) analyses for Design for Automatic Assemblies. Master Thesis. Universiti Teknologi Malaysia, Malaysia.

APPENDIX A

Design for Assembly Worksheet.

0	1	2	3	4	5	6	7	8	9
Name of Part	Part ID #	# of times the operation is carried out consecutively	two-digit manual handling code	manual handling time per part	two-digit manual insertion code	manual insertion time per part	operation time, sec, (2) x [(4) + (6)]	operation cost, cents, 0.4 x (7)	estimation of theoretical minimum # of parts, 0 or 1
	1								
	2								
	3								
	4								
	5								
	6								
	7								
	8								
	9								
	10								
	11								
	12								
	13								
	14								
	15								
	16								
	17								
	18								
	19								
	20								
							TM	CM	NM

APPENDIX B

Gantt chart for Final Year Project 1

	Activities \ Week		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	First meeting with supervisor and get idea about DFMA	Plan																
		Actual																
2	Select product	Plan																
		Actual																
3	Study DFMA method (Boothroyd Dewhurst)	Plan																
		Actual																
4	Dissasemble and assemble product	Plan																
		Actual																
5	Slide preparation	Plan																
		Actual																
6	Presentation	Plan																
		Actual																
7	Report Writing of chapter 1 : Introduction	Plan																
		Actual																
8	Report Writing of chapter 2 : Literature Review	Plan																
		Actual																
9	Report Writing of chapter 3 : Methodology	Plan																
		Actual																
10	Report Writing of chapter 4 : Prelimanary Result	Plan																
		Actual																

APPENDIX C

Gantt chart for Final Year Project 2

Item	Activities \ Week		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Hitachi AEM study	Plan															
		Actual															
2	Assemble and dissasemble product	Plan															
		Actual															
3	Modelling of redesign product	Plan															
		Actual															
4	Analysis on critical point of redesigned parts	Plan															
		Actual															
5	Slide preparation	Plan															
		Actual															
6	Presentation	Plan															
		Actual															
7	Report Writing of chapter 4 : Results and Analysis	Plan															
		Actual															
8	Report Writing of chapter 5 : Conclusion & Recommendation	Plan															
		Actual															